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GYPSUM

INFORMATION CONCERNING GYPSUM AND A NEW ALL-PURPOSE BUILDING MATERIAL

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GYPSUM

INFORMATION CONCERNING GYPSUM AND A NEW ALL-PURPOSE BUILDING MATERIAL

MEMORANDUM

SEPTEMBER 18, 1952.

To: Hon. John R. Murdock, Chairman, Interior and Insular Affairs Committee.

From: George H. Soule, Jr., Committee Consultant on Mining and Minerals.

Subject: Gypsum Building Material Developed by Lewis C. Karrick.

In accordance with your request, I have gathered and studied material pertaining to the all-purpose calcined gypsum aggregate building material developed by Mr. Karrick, and to gypsum in general, with the possibility of utilizing this new building material for the construction of better housing by the Indians of the United States as the objective in mind. Selected material on the subject is attached.

It appears to me that this new material could be produced easily and cheaply under cooperative or tribal endeavor on or near many Indian reservations. Under such an endeavor, where each participant would contribute his share of time required by the over-all project, the cash cost to each participant or to the tribe for the material in place in a home or other structure should be quite small. The cash or out-of-pocket cost probably would entail little more than (1) the initial cost of a small, relatively inexpensive processing plant which would be amortized over a period of years; (2) one or more trucks; (3) a few items of mining or quarrying equipment; (4) maintenance and repair to equipment not performed by participants; and (5) operating supplies.

GYPSUM DEPOSITS ON INDIAN RESERVATIONS

Attached is a map showing the Indian reservations of the United States on which the approximate locations of the principal gypsum deposits have been marked by the United States Geological Survey. This information is based primarily on data obtained from a bulletin published by the United States Geological Survey 32 years ago. Consequently, there probably are many deposits located on or near Indian reservations which are not shown on this map. For example, you have visited and have obtained samples from a gypsum deposit on the Colorado River Indian Reservation, and have obtained samples from a gypsum deposit on the San Carlos Indian Reservation in Arizona, which deposits are not shown on this map.

FREE USE OF PATENTS BY INDIANS

As you wish to have a committee print made of useful information pertinent to the subject, there is attached a copy of the letter recently submitted to you by L. C. Karrick in which he offers the Indians of the United States free use of the patents covering the new building material and method of manufacture which he developed.

SCHEMATIC DRAWING OF PORTABLE PLANT

Mr. P. B. Eckels who now is in the organization of a large rubber company and who has had many years' experience in the design of mining, milling, and other machinery kindly supplied the attached schematic drawing of a 2-ton per batch portable gypsum calcining plant for producing the material covered by Mr. Karrick's patents. There also is enclosed a letter of transmittal from Mr. Eckels.

Mr. Eckels estimates that the portable calciner shown in his drawing would not cost more than $12,000 to $15,000 at this time and that a semiportable plant built on a hillside so as to obtain the benefits of gravity flow would eliminate the trailer, conveying equipment, and other items, and probably would cost half as much, or $6,000 to $8,000.

Two hours are required to completely calcine a batch of raw gypsum crushed to pass through a three-fourths-inch screen. Therefore, this 2-ton calcining plant would produce an average of 1 ton per hour of completely calcined gypsum aggregate or pebbles. By calcining the raw gypsum for 1 hour a partially calcined product of a lower compressive strength is obtained, as is shown in table 2, specimens C7, C8, and C9, of the attached Bureau of Standards report. I should think that partly calcined aggregate which, when cast into blocks, give compressive strengths of 480 to 590 pounds per square inch would be adequate for the purpose, in which case, a 2-ton calciner such as that designed by Mr. Eckels would produce 2 tons per hour. The crusher, boiler, screens, and hoppers should readily serve a second rotary calcining unit in the semiportable plant referred to here. Therefore, the addition of a second rotary calcining unit should double the capacity of such a plant without greatly increasing the cost.

MANUFACTURE AND USE

Many Indians have worked in the mines. Participants with such experience could easily mine or quarry the rock gypsum.

Operation of a small calcining plant, which probably would require two or three men per shift, could be carried on by participants experienced in handling machinery after being given a short period of training in the use and care of the equipment and in the proper forming of the gypsum blocks.

The construction of homes and other small structures, and the maximum utilization of gypsum in such construction should be mastered by the Indians without difficulty once they are given proper instruction and information in regard thereto.

One of the advantages claimed by Mr. Karrick for this new material is that no mortar joints are needed, and, therefore, that one does not need the experience of a mason in order to lay the blocks. This would require (1) that the molds be made with great care so that each block

is true and exact and has identical dimensions; (2) that the first course of blocks be laid with considerable care so that the course is true and level; and (3) that each joint be clean and free of any particles that would interfere with the proper laying of the blocks.

BUREAU OF INDIAN AFFAIRS

Much could be done by the Bureau of Indian Affairs at a relatively small cost to help the Indians obtain a good start in the use of this building material.

Further determinations as to the maximum utilization of this material in small-home construction should be made. Simple instructions and specifications must be worked out for each application. Designs of homes and other structures of simple construction, adapted to the use of this new gypsum material and to the needs and desires of the Indians should be prepared for their use. It probably would be necessary to furnish some training and guidance by demonstration in the construction of homes made of this new material during the initial stages of a cooperative or tribal endeavor.

The Bureau of Indian Affairs should be able to provide this assistance if it chose to do so. In fact, the Bureau could be expected to welcome the opportunity and challenge presented by this new building material. However, a desire and determination to succeed, coupled with creative and technical abilities, on the part of those who might be assigned to such a project would appear to be essential for the ultimate success of such an undertaking by the Bureau.

NATIONAL BUREAU OF STANDARDS REPORT

There is one serious deficiency in the Bureau of Standards report. Analyses of the materials used, which are essential information in all determinations of strength and other properties of materials of this nature, were not made or reported by the Bureau. The fact that anhydrite and other undesirable materials which lower the strength of gypsum materials generally occur in gypsum deposits makes it important to know the amount of such diluent materials in the gypsum product being tested. Generally speaking, under identical conditions, the greater the amount of anhydrite present in a test sample of calcined gypsum aggregate concrete, the lower the compressive strength that will be obtained.

Mr. Karrick reports that a sample of this Virginia gypsum which he privately analyzed following the strength tests made by the Bureau of Standards showed a 30-percent anhydrite content. Mr. Karrick also points out that, contrary to the statement in the report, he did not furnish the gypsum from Virginia used in the tests, but that this material was furnished by the United States Gypsum Co. on the approval of the National Bureau of Standards.

For reasons which need not be discussed here in detail, the maximum pebble size (½-inch) used in the specimens tested appears to be too large in relation to the size of the specimens for best results. It should not be overlooked that one-half or less of the diameter of the pebbles forming the vertical surfaces of test specimens or building blocks made of the subject material are not supported. This lowers the compressive strength in relation to the gross area. For this reason,

blocks of larger cross sections, using the same size pebbles, would have given a truer measure of the compressive strength of the material.

By troweling or otherwise embedding calcined gypsum pebbles (moistened sufficiently to yield and adhere to a surface) into the voids between the pebbles of the vertical surfaces of test blocks or of erected walls and partitions, the surface and compressive strengths should be increased significantly and other highly desirable properties would be imparted.

In conclusion, it is my opinion that the calcined gypsum aggregate building material developed by Mr. Lewis C. Karrick may afford a means by which more healthful, comfortable, and attractive homes may be acquired by many Indians of the United States; an improvement which you have long desired to bring about.

SEPTEMBER 3, 1952.

Hon. JOHN R. MURDOCK,
Chairman, Committee on Interior and Insular Affairs,
House of Representatives, Washington 25, D. C.

DEAR CONGRESSMAN MURDOCK: Confirming past discussions with you in regard to our plans for assisting the housing projects of the Indians of the United States, and as I have stated to the Bureau of Indian Affairs, I will be glad to give the Indians the free use of my patents on new gypsum structural products and processes for their own city and farm structures.

For the sale of the products to other people living off the reservations, I would want to receive some share of the profits obtained by the tribes or Indians who arrange with me to use the patents.

As you know from the United States map supplied your Washington office, large gypsum deposits are to be found on or near many of the Indian reservations. Our pilot and commercial-scale plant studies made at a number of State universities showed the advantageous uses of the new material for low-cost structures. Indian groups, with proper, low-cost equipment, could make this gypsum building material on their reservations and build beautiful, comfortable, and permanent homes and other buildings with it as easily and probably more cheaply than with adobe or other materials.

Very truly yours,

LEWIS C. KARRICK,
P. O. Box 809, *Washington 4, D. C.*

"ALABASTER"

NAME GIVEN TO A NEW ALL-PURPOSE, STRUCTURAL AND INSULATING BUILDING MATERIAL MADE FROM GYPSUM

(By Lewis C. Karrick, E. M., M. S., September 1952)

A new low-cost insulating structural material in various forms has been developed in my researches, and also the plants and processes for its manufacture. It has received considerable study in testing laboratories of leading universities, namely, the State universities of Utah, Minnesota, Wisconsin, Ohio, and Maryland. It can take the place of much of the brick, stone, cinder block, plaster, cement,

timber, and steel now needed in residence and other building construction. The mineral gypsum from which it is made occurs extensively in many States of the United States and foreign countries.

The new product can be manufactured generally throughout the United States from accessible natural deposits of the mineral gypsum and should, therefore, provide a permanent, dependable, low-cost, all-purpose building material. It is fireproof, moistureproof, termite proof, verminproof, and has excellent sound and heat-insulating properties. The material can be applied by anyone with average mechanical skill, in constructing foundations, walls, floors, ceilings, and roofs of residences, and on farms for silos, stock sheds, brooder houses, granaries, walk-in freezers, cold-storage plants, and other auxiliary outbuildings, also for tanks and stock reservoirs; for such light construction as stores, garages, tourist courts, service stations; and for extensive use in office and factory buildings where "curtain wall" construction is used.

This new building material is an artificial "conglomerate stone" and is preferably made at the construction site from evenly sized pebbles of any dimension or from granules of the mineral rock gypsum or alabaster, which have been processed. They set quickly and bond together, giving any desired wall density, strength, and insulating quality. The pebbles, of any selected size, are placed dry into wall or block forms, in layers, and when the water is applied the material joins together and sets hard in less than 1 hour. If desired, its set can be accelerated with common salt or alum to less than 30 minutes, at which time the forms are reused.

The material is manufactured preferably from gypsum rock, which is crushed to gravel size, and is then heated rapidly to certain temperatures in a rotary steam-heated pressure calciner. This steam-heat treatment in the manufacture insures that all of the lumps receive very uniform heating and at exactly the proper temperature throughout, which is vital to making a dependably high-quality product. This is accomplished as the lumps are being rolled and circulated over the steam-heated tubes inside the calciner. The result is that the lumps are worn round, and all surfaces of the lumps are given the same texture and cementitious value. The fine material produced both in the crushing of the rock gypsum, and also in the attrition from wearing of the lumps during the calcining, is a very high grade cement plaster possessing superior sand-carrying capacity, and has been shown to have better working and hardening properties than most present-day commercial wall plasters and molding plasters.

DEVELOPMENT DATES FROM 1917

These mechanical qualities of the products were determined by the usual ASTM methods. Crushing strength determinations were made in the mechanical engineering laboratories at several State universities and at the National Bureau of Standards in Washington, D. C. Much of the research and development studies on the process, plant, and products, were carried out at the University of Utah as a thesis for graduation in the Mining and Engineering School in 1917, following my 4 years of work serving as chemist and superintendent of a gypsum-products company in Utah.

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Then I was overseas in World War I, and on returning in 1919, I resumed this gypsum products study while employed in Utah in the cooperative investigations of the oil shales, hydrocarbons, and coals of the United States by the United States Bureau of Mines and the State of Utah. Finally, in the period 1930–38, while supervising the oil-from-coal researches of students at the University of Utah, I simultaneously conducted extensive studies of gypsum deposits of the West and development work on gypsum plant, process, and products, as a candidate for an M. S. degree in mechanical engineering.

PATENT COVERAGE

Four patents have thus far been issued, namely, No. 1,897,259—Apparatus, issued February 14, 1933; No. 1,967,029—Process, issued July 17, 1934, covering "exploding" gypsum while heating in an electric calciner, both of which patents are now expired. Also there are No. 2,274,705—Product and Method of Making, issued March 3, 1942; and No. 2,479,576—Apparatus for Making Building Material, issued August 23, 1949, which covers certain types of portable gypsum-products plants. Also other patents will be filed on new light-weight insulating gypsum products of record which have been developed and for which there is a large and growing need in both the rural and urban areas of the United States.

LIGHTWEIGHT STRUCTURES OF STRENGTH AND BEAUTY

When the crushed, gravel-size gypsum is calcined to the proper degree it is then dropped from the calciner (a fresh charge of raw material taking its place) and is screened into all of the sizes suited to the builders' needs. The size (between three-fourths and one-half inch) has been shown to be excellent when used in walls or blocks of above 6 inches thick, and the size (between one-half and one-fourth inch) for walls above 3 inches thick, and size (between one-fourth and one-eighth inch) for walls, blocks, partitions, or roof slabs 1½ to 3 inches thick. The size (—one-eighth inch to dust) is suitable without pulverizing for wall plasters, reinforced roof slabs, and for molds for pottery, fresco, movie sets, and so forth.

When this —one-eighth inch gypsum product is placed in water, in either a vat or a plaster mixer, the granules immediately disintegrate into a smooth paste, and it has been found to have superior spreading quality and sand-carrying capacity to many of the best commercial plasters. If its use required a slow or delayed set, from its 15 to 30 minutes normal setting time of plaster of paris, then the usual chemical retarders in liquid form are added to the mixing water.

WALLS FROM BLOCKS

In erecting a wall of the sized-lump product, either the wall may be cast in place in successive layers, on a foundation of this same or other material, or blocks may be cast alongside the wall and immediately laid in place without mortar. The blocks of set material do not require aging or seasoning before installation, since the set is hard enough for safe handling of the blocks in 40 minutes; in 60 minutes it is quite hard; and in 24 hours, if dry, will have approached near to its final

greatest strength. A thin mixture of fine plaster and water of about the consistency of cream is painted on the contact surfaces of the blocks as laid, or, if the blocks are grooved, the thin mixture is poured down between grooved ends of adjacent blocks. This method is used for the joining of many blocks at one time throughout the whole length of the wall.

CASTING THE WALL IN PLACE

The wall "forms," say 8 inches high, and spaced 8 inches apart, are set in position, and are filled level full with the dry granules, being careful to prevent the lumps arching against the forms and creating cavities. Then a gentle deluge of water is poured over the material, being sure that all lumps are simultaneously and thoroughly wetted. If blocks are being cast the form and contents may be dipped in water for 5 to 10 seconds depending on the size lumps used. The excess water immediately runs off and the granules absorb just the amount of water that causes them to set; that is, return to rock gypsum, and bond together very solidly. This product contains no excess water as do all plaster mixtures. After 2 or 3 minutes the lumps will be found to have softened slightly and at this point the mass may be compacted together to any extent desired. This may be accomplished by sudden applied pressure or by use of vibrators.

A HIGH-STRENGTH PRODUCT

Many determinations have been made on many test blocks of different-sized granules and densities, and from different gypsums of the United States and Canada, and it has been shown that the average block made as described above, with no compacting or compression after wetting, will have a minimum crushing strength of 350 pounds per square inch or 50,000 pounds per square foot. With only 15 percent compacting after wetting a compressive strength of 1,200 pounds or more per square inch can be obtained. At 30 percent compacting the voids between the granules will have largely disappeared and the strength will be well above 1,200 pounds per square inch.

Obviously, the wall with the least compacting; that is, with the greatest percentage of air cells, will have the best heat and sound insulation properties. However, a wall composed of blocks or layers in which the material has been compacted 15 percent should have a compressive strength equal or better than concrete masonry walls made of "cinder" or "cement" blocks. Also, its insulating value will be about the same as porous cement blocks. It should be emphasized that the pebbles of gypsum when set are nonporous, they do not absorb any water, and are as hard as the original rock.

SIMPLIFIED CONSTRUCTION METHODS

Movable wall forms, 8 inches high, may be placed so that they can be raised up 8 inches every 40 minutes after each course or layer is set. Also (if making blocks) the block forms may be emptied each 40 minutes. Hence, on the job there should be ample block forms to turn out blocks as fast as the bricklayer or mason can put them in place. Two 10-inch boards, one on each side of the wall, arranged to slide up 8 inches as each course is laid, behind rigid guideposts, have

been found to be satisfactory and cheap forms for constructing a wall. It requires no wire ties to prevent bulging or distortion of the forms and uses only a small fraction of the lumber needed in the customary cement-concrete forms. Also, these movable forms are reused many times and suffer no damage after repeated uses. Well-oiled waterproofed lumber (or plywood) should be used for the forms that contact with the wet gypsum granules, and it has been found effective to apply soap solution or lard oil to these surfaces as the layers of material are placed.

Other forms of hard rubber, plastics, aluminum, aluminum alloys or stainless steels, thin and rigid, are still better than those of wood, and may be used on many jobs. Steel forms rust quickly and will discolor the walls. As the walls are raised, doors and window frames are set in place inside the wall forms. The mass of gypsum granules will set around the frames and anchor them airtight and solidly in place. It has been found best to compact the wall material slightly more where it contacts with a door or window frame, and especially under the bearing points of rafters, posts, floor and ceiling joists, thus giving added strength. Also removable inserts may be cast into the inner surface of the wall to serve as channels or recesses for piping, wiring, radiant heaters, brackets for bookshelves, lighting fixtures, or other wall hangings.

For rapid and low-cost construction, several types of sectional steel forms may be used. These can be set up and taken down quickly in the manner provided by the manufacturer. In some construction it is advantageous to pour the wall in a continuous operation, wetting the cementitious gypsum gravel particles immediately as they enter the wall forms. Also the material may be applied to rubber "air forms" by the airjet or "Gunited."

When the wall is completed the plastering may be done immediately or at any time with equally good results, since the plaster is of the same chemical substance and makes a perfect mechanical and chemical bond. If straight forms have been used the wall surface will be perfectly true so that only one coat of plaster is all that is needed on each surface to make a finished job.

Since the water used in the setting process of this material becomes a chemical part of the finished material, it is frequently desirable to use water in which has been dissolved dyes of attractive colors. This imparts permanent tints to the walls, plain, or it may be variegated. Whether white or colored, close sizing of the pebbles adds greatly to the beauty of the unplastered surfaces; and also to the texture, appearance, and acoustic properties. It is not necessary to plaster or stucco both sides of a wall to make it amply strong and airtight. Walls with exposed small pebbles are most attractive. When the wall is to be covered with plaster it will be found best to use the fine (minus one-eighth-inch to dust) size materials for this plastering. One coat of plaster is ample to give a solid and true wall, which also may be tinted as described above with any desired color.

In a fairly dry climate it is not necessary to waterproof the plastered outside walls of houses made of this material. The pebbles themselves are impervious to penetration of water. The plastered surfaces, neat without any sand, fiber, plasticizer, or other bulking ingredient, will have substantially permanent life where it is subjected to average weathering conditions. Prolonged running water against the plaster

or pebbles, leaky drain spouts, or flashing, can have a harmful dissolving effect ultimately. There are, however, waterproofing "rubber base" paints or impregnating and sealing fillers which are available for use if desired, but these need not be applied for years, or until signs of weathering become apparent. Also a high-lime stucco may be used on the outer surfaces, but dolomite stucco must be avoided.

This calcined cemetitious pebble material, screened ready for use in construction, weighs approximately 75 pounds per cubic foot, and when set and dry weighs 90 pounds or higher if compacted, as compared with 150 pounds for portland cement concrete. It is as light as some portland cement concrete containing lightweight aggregates, and should have universal use in all types of houses and farm buildings, also in office-building construction to back up the face brick, and for all partition walls, making lighter weight buildings.

When used for flooring or roof slabs in residences and farm buildings the material is leveled off in horizontal forms, wet, and then vibrated. For floors it should be rolled or (preferably) tamped solidly. When set and dry the floor is surfaced with a sanding machine and then is given several coats of spar varnish. Linoleum may be cemented to the dry surface, or carpets used and tacked to inset wood strips. Many beautiful effects are produced if colored water is used in the floor, wall, and roof material. The ceiling and roof slabs are cast with a reinforcing of prestressed wires enclosed, the slab edges being shaped to overlap adjacent slabs. When in place a thin grouting of plaster is poured into the contracting grooves or edges of the slabs and, at the same time, the top surface is troweled where needed so as to be free from blemishes. When the roof is perfectly dry the top surface may be waterproofed. It may be coated with tar or mastic, a rubber base paint, or a waterproof felt may be used. Forms for roof slabs may be shaped so as to give the top surface the appearance of shingles or other ornamentation, in which case a fluid waterproofing is applied.

LOW COST OF MATERIAL AND LABOR

This new wall construction has been estimated at sites near gypsum sources throughout the United States to cost less than one-half the cost of hollow cement or cinder-block walls. The railroad, or truck freight, is low since run-of-mine rock gypsum is shipped to points of consumption where processing plants prepare the material for nearby use or delivery to the ultimate user by truck. This saves any cost of packaging, warehousing, or other handling.

Repair work on a damaged wall or partition of this material is relatively simple and inexpensive as compared with repair of hollow walls of wood, tile, or furred cinder blocks. This wall, if desired, may be easily constructed with hollow blocks or ducts inside the walls, which will reduce the weight of material used and may add somewhat to the economy, insulation, and other qualities of structures.

WATER RESISTANCE

The following data will show the exceptional water resistance of this new structural material and the extensive use that may be made of this material for exterior and other applications.

In the 1951 edition of the Handbook of Chemistry and Physics, page 1470, it is shown that gypsum may be dissolved in pure water to

the extent of 2.23 grams in 1,000 cubic centimeters, of water at 0° C., and 2.05 grams at 100° C., the boiling point of water. This solubility is determined under laboratory conditions by using finely pulverized gypsum stirred in water over a long period of time so that each molecule of water comes in intimate contact with the powdered gypsum—a condition that would not exist when this new gypsum material is used for the exterior walls of buildings where it would be exposed to rainfall.

Taking 2.2 grams of gypsum per liter of water as the average solubility, 1 cubic foot or 28.316 liters of pure water will dissolve 62.29 grams of gypsum, which equals 0.1367 pounds per cubic foot water, under the conditions described above. Since solid rock gypsum has an average weight of 144.54 pounds per cubic foot, a 1-inch layer of the cube would weigh 12.05 pounds. Theoretically then, 10 inches, or 0.833 feet, of rainfall per year per square foot of area, which is the average yearly rainfall for Arizona, would dissolve 0.1139 pounds (0.833 feet by 0.1367 pounds) of solid rock gypsum per square foot each year on the above basis of solubility. Therefore, a 1-inch slab of solid rock gypsum 1 square foot in area would require 105.8 years (12.05 pounds divided by 0.1139 pounds) to be dissolved by 10 inches of annual rainfall.

Actually, a 1-inch slab of solid rock gypsum 1 square foot in area would have to be finely pulverized and each year's rainfall (10 inches per square foot) would have to be caught and intimately mixed with the pulverized gypsum until each molecule of water becomes saturated with gypsum before allowing it to run off in order to be dissolved in 105.8 years. Nothing approaching these conditions or rate of solubility would be found as a result of rainfall on the walls or roofs of buildings constructed of solid rock gypsum or the new gypsum building material described above. In fact, in an area with 10 inches of annual rainfall it might well require 800 to 1,000 years or more for the rain to dissolve 1 inch of unprotected exterior wall or roof surfaces made of these materials.

Rainfall runs off the walls and roofs of buildings immediately. The tendency of the film of water in contact with a solid surface to adhere and resist removal—called the "film factor" or "skin factor"—would further reduce the amount of rainfall coming in intimate contact with roof and wall surfaces. As a result of the rapid runoff and the film factor, only a small portion of the rain that falls on the walls and roof of a building made of gypsum would have an opportunity for dissolving action. Furthermore, only a minor percentage of this small portion would become saturated during the contact of rain with the gypsum. It also should be pointed out that only a part of the average annual rainfall would fall on any particular wall of a building. When rain falls straight down or at a slight angle little or no rain would wet the walls of low buildings with eaves. Wind-driven rains would wet the walls to the windward sides, leaving the walls to the leeward fairly dry.

In view of the above, it would seem probable that the equivalent of only 5 percent or less of the total annual rainfall of a given community would become saturated with gypsum dissolved from the walls of the buildings and possibly 10 percent or less would become saturated with gypsum dissolved from roof surfaces. The foregoing assumes that these exterior gypsum surfaces are not protected by films or coatings of other materials.

The table below is presented for purposes of comparing the theoretical rate of solubility of a 1-inch slab of solid rock gypsum under laboratory conditions and the probable rate of solubility under these natural conditions as discussed above:

	Minimum time to dissolve 1 inch under laboratory conditions—gypsum pulverized and intimately mixed with water until dissolved	Probable minimum time required to dissolve 1 inch of unprotected wall surface, under natural conditions—gypsum in solid form and with immediate run-off of water
Rainfall per year in inches:	*Years*	*Years*
10 (Arizona)	105.8	2,116
14	75.6	1,512
20	52.9	1,058
36 (Washington, D. C.)	29.4	588

This discussion of the water resistance of gypsum concerns the solubility of gypsum only and does not include the resistance of or the effect upon gypsum of other weathering actions to which all exterior surfaces are subjected, nor the effect of many protective paints or coatings.

Instructions for Making Small Test or Demonstration Blocks From Calcined Gypsum Pebbles

(By L. C. Karrick, August 1952)

GENERAL

In casting blocks from pebble-sized calcined gypsum, various methods have been found to give very good results. A satisfactory method is given here.

Blocks may be made of material screened to a certain size or they may be made of pebbles of mixed sizes. However, the smaller the casting form, the smaller the size of pebbles that should be used. A strong, well-filled test block will not be obtained where the pebbles used are too large in relation to the size of the form used. For instance, calcined gypsum pebbles that will pass through a screen with 1 inch openings and remain on a screen with ½-inch openings (—1- to ½-inch size) would be suitable for casting solid building blocks measuring 8 by 8 by 12 inches but would be much too large for good results in casting a 3-inch block; while pebbles which will pass through a screen with 7/16-inch openings and remain on a screen with 9/32-inch openings (—7/16- to 9/32-inch size) are satisfactory for use in casting a 3-inch block, pebbles of this size are a little too large for casting a 2-inch block.

PROCEDURE

1. Coat the inside surface of metal forms with a very thin film of a lubricating substance to prevent the forms from sticking to the gypsum block. Lard oil, any soft soap, cold cream, shaving soap, etc., may be used. Motor lubricating oil should not be used because it will discolor and damage the pebble surface.

2. Pour calcined dry gypsum pebbles into form and fill to overflowing. Vibrate the form for a few seconds while pouring the

pebbles so as to prevent cavities from occurring by arching of the pebbles against the walls. Additional vibration will further compact the mass if it is so desired.

3. Immerse the form and contents in water for about 5 seconds, remove and permit the surplus water to drain off through the perforations in the bottom of the form.

(NOTE.—Permanent colors of attractive tints and shades may be imparted to the blocks by using water colored with bluing or other suitable dyes.)

4. Vibrate again if a more compact and stronger block is desired. Excessive vibrations or downward pressure on the softened pebbles will cause the spaces between the pebbles to be filled. This will give a stronger block but much of the heat and sound-insulating value will be lost as the voids disappear, although the block density and strength is increased.

(NOTE.—Many studies have proved that these blocks or sections of wall are as hard and strong as the average brick and mortar wall even though the gypsum pebbles are not vibrated or pressed down in the form while either dry or wet.)

5. Remove the block from the form after waiting at least 40 minutes, at which time the block will have set to a hardness which will permit handling. A little salt added to the water will cut the setting time 50 percent.

TO COAT SURFACE OF BLOCK WITH PLASTER

The —⅛-inch to dust size of calcined gypsum will readily form a very smooth-working plaster mass without further pulverizing. It will set hard in about 15 minutes after the water and fine product are well stirred together. This plaster material will dry out to a snow-white color in about 24 hours and will be very hard. It will have one-half the strength of portland cement.

(*a*) Place desired amount of the —⅛-inch to dust-size material in a cup or bowl, add water and mix well. Continue with additions of water and mixing, if necessary, until the mass becomes uniformly plastic and is smooth-working.

To test, place a small amount of the plastic mixture on a piece of glass or other smooth surface. The plaster should barely retain the irregular shape formed when deposited. If it slumps into a smooth-surfaced mass it contains too much water and it would not adhere to a wall. Therefore, more dry plaster material should be added until the proper consistency has been obtained.

(*b*) Quickly scoop up the wet plaster and apply to the surface of the block with a spatula or other tool.

A smooth surface may be given to the ends of a block as soon as it is cast and before it has set by applying plaster to the top surface and scraping it off even with a spatula or by pressing it down with a piece of glass which will cover the top of the form. To apply plaster to the opposite surface, place a piece of glass on top of the form and turn the form upside down; remove the perforated bottom; and repeat the plastering procedure as described for the top.

Any thickness of plaster may be applied to the ends of a hardened block by first wetting the surface of the block to be coated, and then applying the mixed plaster as described above.

Patented Mar. 3, 1942 2,274,705

UNITED STATES PATENT OFFICE

2,274,705

BUILDING MATERIAL AND METHOD OF MAKING THE SAME

Lewis C. Karrick, Salt Lake City, Utah

No Drawing. Application November 24, 1937, Serial No. 176,279

3 Claims. (Cl. 106—110)

This invention relates to building material and methods of making it, and more particularly to non-conducting building material of calcined gypsum and methods of making same.

Heretofore it has been a practice in some instances to prepare gypsum by finely pulverizing and subjecting it to dry heat while agitating it. Pulverizing has been employed primarily in order that the mass will become aerated and easily stirred in the mixing which accompanies calcination in the well-known kettle processes. Fine pulverizing requires a burdensome expense for machinery and power, and I have found that great economy is effected by eliminating pulverizing and, instead, merely breaking the rock gypsum down to granular sizes.

It is therefore an object of this invention to provide a method of making building material which will be efficient, quick, and economical in the pre-calcination operations.

It is old to calcine gypsum by subjecting it to open flame in a rotary kiln, but experience has established that such practice produces a yield of varying quality, besides frequently resulting in over-heating or under-heating the gypsum. In United States Patents Nos. 1,897,259 and 1,967,029, issued to William Leon Ellerbeck and me, is disclosed an internally heated drum wherein the powdered gypsum is calcined by tumbling it over tubes heated by electrical resistors. Recent experiments have established that better calcination is obtained if the heating is accurately controlled as to temperatures, and this is done in the present instance by heating the gypsum in an insulated tumbler drum having internal tubes for high pressure steam so that every point in the calciner is at exactly the same temperature.

It is another object of the present invention to provide for the calcination of gypsum material rapidly, conveniently, and under conditions which enable absolute control of the quality of the product.

It is another object of the invention to provide a method of calcining gypsum whereby the gypsum is subjected simultaneously to stirring by a controlled heating member without accidental overheating or under-heating of the gypsum.

It has been observed, heretofore, that in the preparation of plaster with powdered gypsum, only a small portion of the mix water unites chemically with the gypsum, the larger proportion of the water evaporating from the plaster and leaving pores or voids throughout the body thereof. By mixing the plaster from a desired proportion of my granulated gypsum, I form a cellular product with no air pockets whatsoever in the cell walls, thereby obtaining a very strong

plaster. Or, by sizing the granules and using certain proportions of some sizes, it is feasible strictly to control the gross density and strength of the final product.

In addition, it has been discovered that by pressing and/or immediately agitating the mix after adding the water, the density of the final product will be substantially increased. If desired, the granular body may be made with large voids, as by pouring off the surplus water. Also, the cost of the product may be reduced by mixing in certain proportions of raw gypsum.

It is, therefore, a futher object of the invention to provide a plaster body which will be durable, strong, and economical to manufacture, and a method for making same whereby the physical properties of the final body may be easily controlled.

Among additional objects of the invention are the production of a building body of high strength and low heat conductivity and with good acoustic properties, requiring but a small amount of labor in its preparation on the job, as well as a body easily manufactured of several different types of gypsum.

A substantial view of the prior art for calcination of powdered gypsum may be obtained by reference to the patents enumerated above. In the practice of the present invention, the rock gypsum is dumped into any suitable mill and crushed to a granulated, as distinguished from a powdered, size. This operation incidentally will result in the powdering of some of the gypsum, but the powdered portion is salvaged and utilized in accordance with the invention.

The crushed product is then subjected to calcination in the tumbler or revolving drum including internally disposed heating tubes through which is circulated high pressure steam. It has been found that by jacketing the rotary calciner with several inches of good insulating material, the granular gypsum is efficiently and accurately heated by contacting with these tubes. The precise values employed in the treatment may vary somewhat in relation to the properties of the particular material being calcined. However, I have found that the invention may successfully be practiced with a standard high-grade gypsum as follows:

The steam may be heated to 67 pounds absolute (300° C.) in a boiler and delivered into the heating tubes without drop in pressure, and this saturated steam temperature has been found to be high enough to calcine gypsums to the "first settle" stage. I prefer, however, to use saturated steam of at least 75 pounds pressure (308° F.) in order to obtain more rapid heating and thereby speed up the process. If it is desired to calcine to the "second settle" stage, it has been found that a saturated steam pressure of 96 pounds per square inch (325° F.) is adequate, although the process may be expedited if the steam is used at a higher pressure. In producing "first settle" plaster, it is important to keep the steam temperature close to the final temperature desired for the plaster product in order to avoid some of the gypsum becoming calcined considerably beyond the half-hydrate stage with the well-known effects on water absorption, strength, heat of setting, as well as other properties of the product. However, if a "second settle" product is desired, steam temperature may be considerably above that corresponding to the temperature at which this product is formed, since I have found that the plaster qualities do not change much if the temperature corresponding to "second settle" is

exceeded, that is until the temperature passes 400° F. Consequently, in producing "second settle" plaster, I often use saturated steam in the heating tubes at 200 pounds absolute pressure, which corresponds to 382° F.

In the above operation, the heating by high pressure steam has not only been found to admit of precise control to enable a desired quality in the product, but it is also economical. For example, distilled water may be used in the steam system and vaporized to form steam. Obviously the heat delivered to the gypsum is the latent heat of condensation of the steam, the water thus formed being continuously returned to the boiler wherein it is re-vaporized as fresh steam for further calcining work. By thus continually re-using the distilled water, it is necessary at rare intervals to add fresh water to the system, only in amount to compensate for losses due to leakage from pipe joints or connections.

In the calcining phase, therefore, no fire is brought into contact with any part of the calcining equipment; in fact, the furnace may be located at a remote part of the manufacturing plant. It will be observed that every point in the rotary calciner is at exactly the same temperature so that no over-heating or under-heating of the gypsum is possible. Thus the process avoids the uncertainties characterizing the kettle type calciner used heretofore.

To understand the third or plaster-forming phase of my invention, it will be necessary to bear in mind that whereas most commercial gypsum plasters require between 55 and 65 grams of water to 100 grams of plaster in order to produce the state of plasticity described by the American Society for Testing Materials as "testing consistency" (this being a consistency approximately the same as that used in plastering walls), the plaster in setting takes into chemical union only approximately 15% of its weight of water. The balance of the 60 parts of water, that is from 40 to 50 grams more or less, finally evaporates from the mass, thereby forming pores or voids in the product in addition to those formed by air bubbles. Because these voids ordinarily are evenly distributed through the mass, the resulting product has many thin celled walls, causing the product to lack the desirable strength. While in my new composition material I do not avoid all air pockets, I do, however, form a cellular product which is entirely lacking in air pockets in the cell walls. It is also practicable, in the practice of the invention, to vary the size of the cells and thickness of the walls to any dimensions desired. The following operations have been employed satisfactorily in the production of the improved building material:

The granular calcined product obtained by the steps described above is screened as it comes from the calciner so as to remove all of the finer material, such as that below 16 mesh screen size. The finer material thus removed has been found to mix into a very smooth grain-free mass which I use for wall covering or for casting. The dust-free granular calcined gypsum is then used to form the new composition. The new composition is obtained by placing the dry material in molds, such as brick, block, or wall forms. Then water is poured into the forms so as thoroughly to wet the mass of granules. The mass will be found to settle together somewhat as the contact points of the granules soften and press together, due to the softening effect of the water in the voids between the lumps. In a few moments

the mass sets, by which time the lumps have absorbed water throughout. The mass can then be taken from the molds, or the forms may be removed as the case may be, and the material permitted to finally harden and thoroughly dry out.

The primary advantage of my new product for use as a building material is due to its hardness. The wetted granules take up approximately 15% by weight of water, leaving no air pockets within them, and thus return to the hardn ss of the original rock gypsum. The granules are cemented together at their points of contact by the rehydrated gypsum, the density or hardness thereof being greatest where the pressure is greatest, that is between the granules where the water is largely squeezed out of the plaster-water mixture. Obviously this cementing zone is less dense as the distance increases from the center of greatest contacting area between the granules. The cementing film tends to eliminate the angularity of contact between the granules so that voids in the final mass become rather rounded.

From the foregoing it will be observed that the method is quite rapid, and it requires no mixer or mixing box; furthermore, there is no need for installing pulverizing equipment in the plant or power for driving same.

The invention is applicable to the production of building material to suit various specific requirements. For example, the size of the granules may be varied to control the size of the voids between granules and, therefore, the gross density of the final product. I have found that slight agitation of the mass immediately after adding the water causes settling, and this will greatly increase the density of the final mass besides increasing the conductivity and hardness of the product. Conversely, the heat and sound insulating properties may thereby be decreased. The acoustic properties of the material may thereby be pre-determined with convenience and reliability. It will be understood, therefore, that the density or percentage of voids in the mass can be easily controlled for any particular job merely by agitating the mass, also by applying pressure after the water is added. Any surface voids may then be filled with finishing plaster and waterproofed.

The nature of the product may also be controlled by utilizing for the mix carefully sized masses of the granules; and in some instances this may be still further employed with immediately pouring off the surplus water which has not been absorbed into the granules. This operation increases the size of the voids in the final product. Furthermore, in order to reduce the cost of the finished material, it is feasible to substitute granules of cleansed raw gypsum for some of the calcined granules. Upon setting, such mixture develops a very strong bond between the rough surfaces of the raw gypsum and the rehydrated plaster. In the latter instance, the technique may be further changed so as to have proportions of both raw and calcined gypsum, and in various screen sizes. This operation may be controlled to produce a dense aggregate so that when the wetted mass is pressed, a very hard flooring or block plaster is obtained. When this is set, dried, sanded down, and varnished, a very beautiful surface is obtained. The method has been practiced and very fine product has resulted using granules up to 1 inch in diameter.

It is obvious that various changes and modifications may be made in the details of steps and quantities of the above specifically described embodiments of this invention without departing from the spirit thereof, and both method and product of the present invention include all such changes, modifications, substitutions, and equivalents as come within the scope of the following appended claims.

What I claim is:

1. A gypsum plaster composition adapted to use in building blocks, bricks, walls, and ceiling fabrication comprising uniformly sized coarse lumps of calcined gypsum which have been rehydrated while maintaining the relative positions of the said lumps substantially constant.

2. A gypsum plaster composition adapted to use in building blocks, bricks, walls, and ceiling fabrication comprising uniformly sized coarse lumps of calcined gypsum which have been rehydrated in contact with lumps of raw gypsum while maintaining the relative positions of the said lumps substantially constant.

3. A method of forming an element of building construction which comprises calcining lumps of gypsum, placing the said lumps in position to define said element, and rehydrating the lumps while maintaining the relative positions thereof substantially constant.

LEWIS C. KARRICK.

Aug. 23, 1949. L. C. KARRICK 2,479,576

APPARATUS FOR MAKING BUILDING MATERIAL

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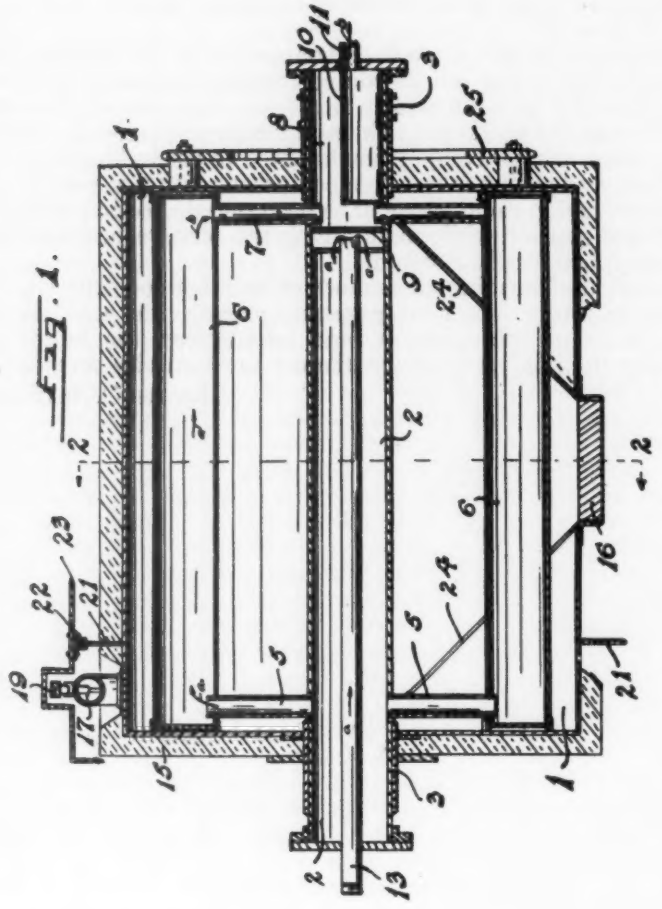

Fig. 1.

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APPARATUS FOR MAKING BUILDING MATERIAL

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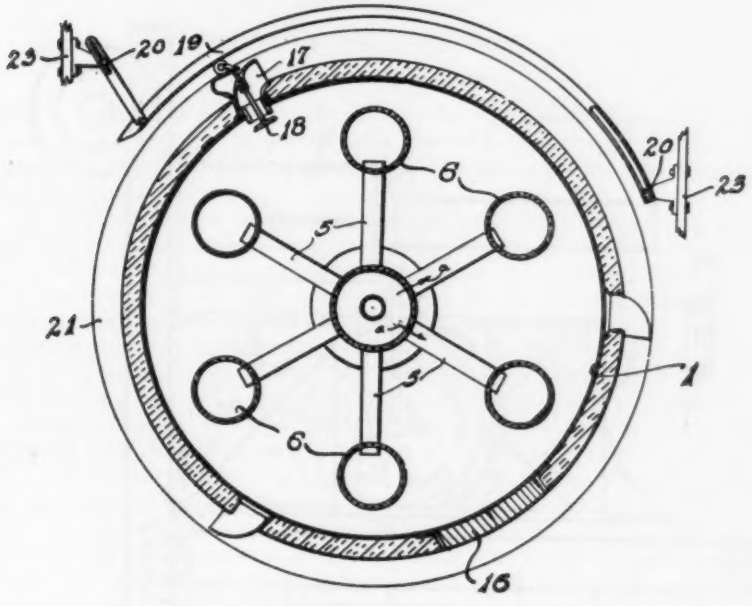
Fig. 2.



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APPARATUS FOR MAKING BUILDING MATERIAL

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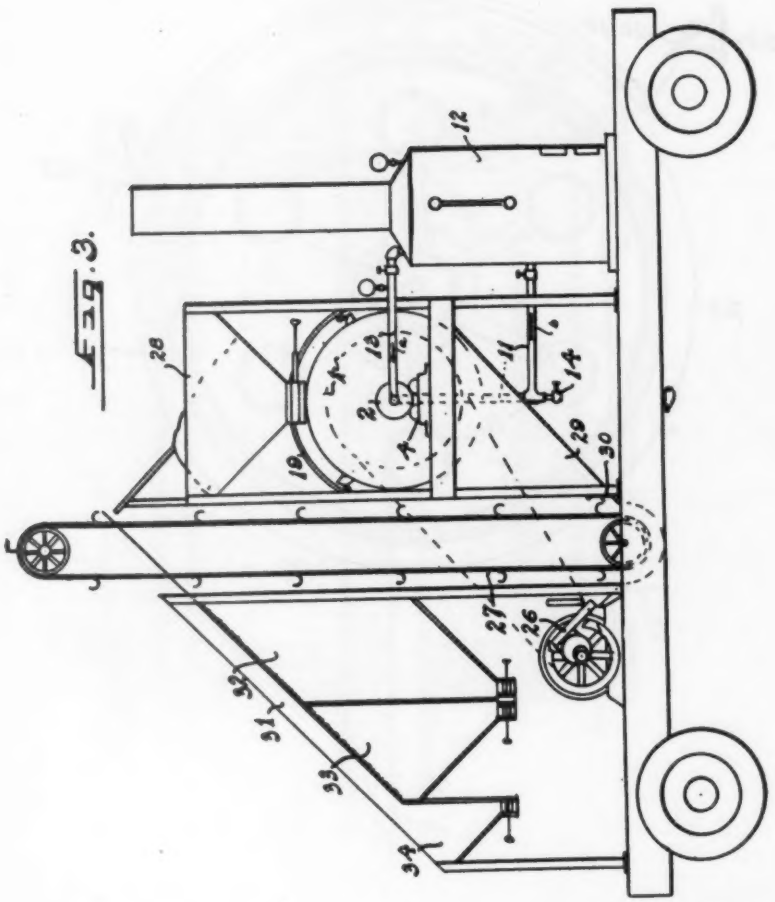
Fig. 3.



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Patented Aug. 23, 1949 2,479,576

UNITED STATES PATENT OFFICE

2,479,576

APPARATUS FOR MAKING BUILDING MATERIAL

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Application March 2, 1942, Serial No. 433,064

7 Claims. (Cl. 263—53)

This invention relates to building material and methods of making same, and more particularly to a portable apparatus for making a non-conducting building material of calcined gypsum and methods of making same.

Heretofore it has been the practice in some instances to prepare gypsum by finely pulverizing and subjecting it to heat while agitating it. Pulverizing has been employed primarily in order that the mass will become aerated and easily stirred in the mixing which accompanies calcination in the well-known kettle processes. Fine pulverizing requires burdensome expense for machinery and power, and I have found that great economy is effected by eliminating pulverizing and, instead, merely breaking the rock gypsum down to granular sizes.

Long investigation has brought out the fact that the final cost of gypsum products is largely made up of the freight cost of the gypsum to the factories and of the higher freight cost on the finished products. In my invention I provide a simple and useful portable plant which can be moved to any new building site and convert run-of-mine gypsum into the finished products on the job, the rock gypsum having been delivered to the site at much less cost than is possible by the present practice of shipping in the same tonnage of manufactured gypsum products. Rock gypsum is well distributed in deposits throughout the United States and, therefore, is easily and cheaply obtained. This new low-cost heat and sound-insulating wall material can now be supplied for all building construction and in the present emergency can be used for war structures and for low-cost defense workers' homes, it being both attractive and easily formed into very comfortable dwellings.

It is therefore an object of this invention to provide a device for making building material which will be efficient, quick, and economical in the calcination operations.

It is old to calcine gypsum by subjecting it to open flame in rotary kilns, but experience has established that such practice produces a yield of varying quality, besides frequently resulting in overheating or underheating the gypsum. Furthermore the product is soiled by the products of combustion in the old kiln practice, unless low-cost gas heat is available. In United States Patents Nos. 1,897,259 and 1,967,-029, issued to William Leon Ellerbeck and me, is disclosed an internally-heated drum wherein the gypsum is calcined by tumbling it over tubes heated by electric resistors, and in which apparatus the sudden release of steam from the rock explodes the gypsum crystals. Recent experiments have established that better calcination is obtained if the heating is accurately controlled as to temperatures, and this is done in the present instance by heating the gypsum in an insulated

tumbler drum or chamber having internally-disposed tubes with high pressure steam so that every point in the calciner receives its heat from the latent heat of condensing steam and, therefore, is exactly at the same temperature throughout.

It is another object of the present invention to provide for the calcination of gypsum material rapidly, conveniently, and under conditions which enable absolute control of the quality of the products.

It is another object of the invention to provide a method of calcination whereby the gypsum is subjected simultaneously to stirring by tumbling, and end-to-end circulation while continuously contacting controlled heating members which prevent accidental overheating or underheating of the gypsum.

It has been observed, heretofore, that in the preparation of plasters of gypsum products and water, only a small portion of the added water unites with the gypsum product in the setting, the larger portion of the water merely acting as a "lubricant" and finally evaporates from the set plaster and leaves voids or pores throughout the body thereof. However, the plaster made from my calcined granulated gypsum is a cellular product due to the spaces between the lumps but the cell walls are very dense and have no porosity whatsoever, and, therefore, is a very hard and non-absorptive element. It is known that ordinary plaster when dry is very absorptive to water, and unless it is water-proofed, is not desirable for exterior of buildings. By sizing the granules in my product or by using certain proportions of various sizes, it is feasible to control the gross density and strength of the final product.

In addition, it has been discovered that by pressing and/or immediately agitating the mix after adding the water, the density of the final product will be substantially increased. If desired, the granular body such as cast blocks may be made with large voids, as by pouring off the surplus water. Also, the cost of the product may be reduced by mixing in certain proportions of raw, clean gypsum granules.

It is, therefore, a further object of the invention to provide a plaster body which will be durable, strong, and economical to manufacture, and a method of making same whereby the physical properties of the final body may be easily controlled.

Among the additional objects of the invention are the production of a building body of high strength and low heat- and sound-conductivity and with good acoustic properties, requiring a small amount of labor in its preparation and application on the job, as well as a body easily manufactured from several different types of gypsum.

These objects I accomplish with the device illustrated in the accompanying drawings in which similar numerals and letters of reference indicate like parts throughout the several views and as described in the specification and pointed out in the appended claims.

In the drawings Figure 1 is a longitudinal diametrical section of the main rotary tumbler or calcining chamber.

Figure 2 is a section on line 2—2 of Figure 1.

Figure 3 is a diagrammatic side elevation of the entire portable assembly showing the relationship between the rotary chamber and the boiler, crusher, elevator and charging bin, the discharge bin, elevator and several screens for final products, the power engine not shown, and the trailer support on which the plant is moved to building sites.

This application is a continuation-in-part of my copending application for patent, Serial No. 176,279, filed on November 24, 1937, for Building material and method of making same, now Patent No. 2,274,705, dated March 3, 1942.

A substantial view of the prior art for calcining gypsum may be obtained by reference to the patents enumerated above. In the practice of the present invention, the rock gypsum is crushed to a granulated, as distinguished from powdered, size. This operation incidentally will result in the powdering of some of the gypsum, but the powdered portion is utilized in accordance with this invention.

The crushed product is then subjected to calcination in a tumbler or revolving drum which has internally disposed heating tubes through which is circulated high pressure steam. It has been found that by covering the rotary drum with several inches of insulating material, the granular gypsum is efficiently and accurately heated by contact with the heating tubes. The precise temperatures and other conditions employed in the treatments may vary somewhat in relation to the properties of the particular material being calcined. However, I have found that the invention may be successfully applied with standard high-grade gypsum as follows:

The steam may be heated to 67 pounds absolute (300° F.) in the boiler and delivered into the heating tubes without drop in pressure, and this saturated steam temperature has been found to be high enough to calcine gypsums to the "first settle" stage. I prefer, however, to use steam of at least 75 pounds pressure (308° F.) in order to obtain more rapid heating and thereby speed up the process. I have used 85 pounds pressure in many plant runs with excellent results and the calcination is completed at a rapid rate. If it is desired to calcine to the "second settle" stage, it is found that a saturated steam pressure of 145 pounds per square inch (355° F.) is adequate, although the calcination may be speeded up if the steam is at higher pressure, likewise if the lumps are to be calcined only partway through.

In producing "first settle" plaster, it is desirable to keep the steam temperature close to the final temperature desired for the calcination of the plaster product in order to avoid some of the gypsum becoming calcined beyond the half-hydrate stage with the well-known adverse effect on water adsorption, strength, heat of setting, as well as other properties of the product. However, if a "second settle" product is desired, steam temperature may be considerably above that corresponding to the temperature at which this product begins to form, since I have found that the plaster qualities as regards hardness do not change much if the temperature corresponding to "second settle" is exceeded, that is, until the temperature passes 400° F. Consequently, in producing "second settle" plaster, I often use saturated steam within the heating tubes at 200 pounds pressure, absolute, which corresponds to 382° F.

In the above operation, the heating by high pressure steam has not only been found to admit of precise control of the temperature and of the final product, but it is also economical. For example, distilled water is actually used in the steam system. Obviously the heat delivered to the gypsum is the latent heat of condensation of the steam within the tubes, the water thus formed by the condensing steam being continuously returned to the boiler wherein it is re-

vaporized as fresh steam for further work of calcination. By thus continuously re-using the distilled water, it is necessary at rare intervals to add fresh water to the system, and then only in amounts to compensate for losses due to leakages from pipe joints and connections.

In the calcining phase, therefore, no fire is brought into contact with any part of the calcining equipment; in fact, the furnace and boiler may be located at a remote part of the plant or may be out of doors. It will be observed that every point in the rotary calciner is at exactly the same temperature so that no over-heating of the gypsum is possible. Thus the process avoids the uncertainties characterizing the kettle type calciners.

In order to understand the third or plaster-forming phase of my invention, it will be necessary to bear in mind that whereas most commercial gypsum plasters require between 55 and 65 grams of water to 100 grams of plaster in order to produce the state of plasticity described by the American Society for Testing Materials as "testing consistency" (this being a consistency approximately the same as that used in plastering walls), the plaster in setting takes into chemical union only approximately 15 percent of its weight of water. The balance of the original 60, more or less, parts of water, that is from 40 to 50 grams, finally evaporates from the mass, thereby forming pores or voids in the product in addition to those formed from air bubbles. Because these voids ordinarily are evenly distributed through the mass, the resulting product has many thin celled walls, causing the product to lack the desirable strength. While in my invention and new composition I do not avoid all air pockets, I do, however, form a cellular product which is entirely lacking in air pockets within the cell walls. It is also practicable, in the practice of my invention, to vary the size of the cells and the thickness of the walls to any dimension desired, by proper sizing of the gypsum granules and/or by pressure on the wetted material after it is placed in the wall or block forms. The following operations have been employed satisfactorily in the production of the improved building material:

Granular calcined product obtained by the steps described above is screened as it comes from the calciner so as to remove all of the finer material, such as that below 8 or 16 mesh screen size. This fine material thus removed has been found to mix into a very smooth grain-free mass which I use for wall covering or casting plaster. The dust-free granular calcined gypsum is then used to form the composition. The new composition is obtained by placing the dry material into moulds, such as brick, block, or wall forms. Then water is applied by pouring it over the mass so as to thoroughly wet the mass of granules. The wetted mass will be found to settle together as the contacting points of the granules become wet. In a few moments the mass sets, by which time the lumps or granules have absorbed water throughout. Prior to setting the mass should be pressed if it is desired to increase the density of the mass. When setting has progressed about thirty or forty minutes the blocks can be removed from the forms or the wall forms may be removed, or raised and another layer of the material placed in the wall forms. The material quickly reaches a safe load-bearing strength.

The primary advantage of the new product is its insulating property and hardness. The wetted granules take up only fifteen percent of their weight in setting, as compared with the 50 to 60 percent of water

needed in the mass of pulverized plasters which leaves the latter product relatively soft. My product is, therefore, composed of lumps or granules solidly joined together and of substantially the hardness of rock gypsum. The granules are cemented together at their points of contact by the rehydrated gypsum, and the density and hardness of the bonds being greatest where the contact is best and where the pressure is greatest, that is between the granules where the water is largely squeezed out of the plaster-water contacts. For best rigidity, therefore, the mass should be agitated or pressed slightly only, unless a dense mass is desired in which case greater pressure is used. Obviously this cementing zone is less dense as the distance increases from the center of the contacting area of the adjacent granules. The cementing film tends to eliminate angularity of contact between the granules so that the voids in the final mass become rounded.

From the foregoing it will be observed that the method is quite rapid, and it requires no mixer or mixing box on the construction job; furthermore, there is no need for installing pulverizing equipment in the plant nor power for running same.

The invention is applicable to the production of building material to suit various specific requirements. For example, the size of the granules may be varied to control the size of the voids between granules and, therefore, the gross density of the final product. I have found that slight agitation of the mass immediately after adding the water causes settling, and this will greatly increase the density of the mass besides increasing the heat and sound conductivity and hardness of the product. Conversely, the heat and sound insulating properties may thereby be pre-determined with convenience and reliability. It will be understood, therefore, that the density or percentage of voids in the mass can be easily controlled for any particular job or product merely by agitating the mass, also by applying pressure after the water is added. A wall may be varied in density at different points to advantage, for instance next to door frames where the jar of slamming doors might cause the wall to crack, or over windows and door and to form window ledges, and in buildings where the walls are required to support heavy loads and in present practice pilasters are used. In the latter instance I merely press the material into a more dense element where the pilaster would be required and thus obviate the need for irregularity in wall thickness caused where pilasters are used with other materials.

The nature of the product may also be controlled by utilizing for the mix carefully sized masses of granules; and in some instances this may be still further employed with a desirable effect on the product by immediately pouring off the surplus water which has not been absorbed by the granules. This operation increases the size of the voids in the final product and yet leaves a solid bond or contact between the granules. And furthermore, in order to reduce the cost of the finished material, it is feasible to substitute granules of cleansed raw gypsum for some of the calcined granules. Upon setting, such material developed a strong bond between the rough surfaces of the raw gypsum and the rehydrated plaster. In the latter instance, the technique may be further changed so as to have proportions of both raw and calcined gypsum, and in various screen sizes. This operation may be controlled to produce a dense aggregate so that when wetted it may be pressed into a very hard flooring or block. When this

element is set, dried thoroughly, sanded down, and varnished, a very beautiful surface is obtained. The wear-resisting properties are not as good as a Portland cement floor but it will be satisfactory for residences, with or without rugs. Also a more extended use will be found in floors on which linoleum, rubber compositions and other shock-absorbing coverings are cemented. The method has been applied and a very fine product has resulted with granules up to one inch in diameter, both with and without raw granules embedded therein.

In the drawings, 1 is the rotary tumbler, 2 the hollow shaft on which are mounted wear-resisting tires 3, and 4 denotes roller bearings which support and rotate the tumbler. 5 are steam-distributing pipes connecting hollow shaft 2 with heating tubes 6. 7 are connecting pipes like 5 through which the condensed steam from heaters 6 returns into compartment 8 at the end of shaft 2. The compartment 8 contains within it the steam-tight partition 9, and dipper 10 which elevates the water during rotation of the tumbler and causes it to run out of the compartment through pipe 11 and into the steam boiler 12. High-pressure steam comes from boiler 12 through pipe 13 and enters the tumbler shaft 2 by way of pipe 13, and flexible coupling not shown, and is delivered into a remote end of the shaft near partition 9. The flow direction of the steam is shown by arrows *a*, and the flow of the water formed from condensed steam by arrows *b*, and it will be noted that the steam flows continuously through the shaft and heating tubes, condensing enroute, and is drawn off as liquid at 11. In starting to operate the unit the steam is passed through and out of the system by valve 14, thereby removing all air from the system. Around the tumbler 1 is a layer of insulating material 15. A door 16 is provided to the tumbler which may be of the folding type or any other type that may be clamped into place. A valve 17, comprising a poppet valve 18 and actuated by a peripheral cam 19 is provided for exhausting the steam released from the gypsum undergoing calcination. The cam linkages 20 provide means for setting the period of release of the steam during each rotation of the tumbler and duration of release time. Thus by controlled release of the steam evolved from the gypsum a high pressure may be built up within the tumbler and when suddenly released has been found to explode the gypsum crystals. This feature of the process may account in large degree for the fact that the process has given wall plasters from several commercially used gypsums which is substantially fifty percent higher in sand-carrying capacity than the plaster produced from said gypsums by present plants. A fin 21 is provided which extends around the tumbler, and fits into a sliding groove 22 in the chamber 23 that houses the tumbler 1, thus preventing the dust from valve 17 from getting into the chamber which surrounds the balance of the tumbler. Inside the tumbler 1 are baffles 24 which cause an end-to-center mixing of the gypsum during rotation of the tumbler, and also serve to direct all of the charge of gypsum products out of the tumbler when the door 16 is opened. On the end of the tumbler is fastened the drive gear 25 which, as illustrated, is a sprocket wheel and is powered through a chain and small sprocket wheel not shown.

In Figure 3 is shown a preferred form of my portable plant embodying all of the aforementioned features of my invention, and in addition a crusher 26 which receives run-of-mine gypsum and reduces it to gravel or granules, including some dust-size product. The crusher

delivers into the elevator 27 and thence into hopper 28 which preferably holds substantially one tumbler-charge of gypsum granules.

Also Figure 3 shows a hot chamber 29 into which the calcined product drops from tumbler 1. From this chamber the product is withdrawn by chute 30 into elevator 27 and thence is delivered by deflector, not shown, onto selective screens 31 and into finished product bins 32, 33 and 34. These bins indicate a separation of the product into a dust-size product and two dust-free sizes of granules suited to making the above-described heat and sound-insulating products, flooring material, etc.

It is obvious that various changes and modifications may be made in the details of steps and quantities of the above specifically described embodiments of this invention without departing from the spirit thereof, and the method, apparatus and products of the invention include all such changes, modifications, substitutions, and equivalents as come within the scope of the following appended claims.

What I claim is:

1. A calcining device of the class described comprising a rotary tumbler mounted for rotation on a hollow shaft; a central steam pipe mounted through one end of and concentric with the hollow shaft and adapted for connection to a source of steam; a dividing partition in said hollow shaft; radial connecting pipes extending outwardly from adjacent one end of said shaft; longitudinal heating pipes in said tumbler connected to said radial pipes; return flow radial pipes connected to said shaft adjacent the opposite end and on the opposite side of the partition from the first-named radial pipes; condensate removal means communicating with said hollow shaft for withdrawing condensate from the tumbler; means for introducing material to be calcined into said tumbler; valve means adapted to periodically open and discharge from the tumbler area steam generated therein; and means for removing calcined material from said tumbler.

2. A device as defined in claim 1, including baffle means disposed in said tumbler to cause the material to be thoroughly agitated while undergoing calcination.

3. A calcining device of the class described, comprising a tumbler mounted for rotation; means for rotating said tumbler; a plurality of heating pipes in said tumbler; means for introducing steam under pressure into said heating pipes; means for withdrawing condensate from said pipes; and means for withdrawing calcined material from said tumbler.

4. A calcining device of the class described comprising a tumbler mounted for rotation; means for rotating said tumbler; means comprising a plurality of pipes for introducing steam under pressure into said tumbler to heat said tumbler; and means comprising a plurality of valves spaced about said tumbler, springs for holding said valves closed at times, and mechanism for intermittently opening said valves against the action of said springs for intermittently releasing the pressure of steam which is generated within said tumbler during the calcining process.

5. A calcining device of the class described comprising a tumbler mounted for rotation; means for rotating said tumbler; a plurality of heating pipes in said tumbler; means for introducing steam under pressure into said heating pipes; means for withdrawing condensate from said pipes; and means for intermittently releasing the pressure

of steam which is generated in said tumbler during the calcining process.

6. A calcining device of the class described comprising a tumbler mounted for rotation; means for rotating said tumbler; means comprising a plurality of pipes for introducing steam under pressure into said tumbler to heat said tumbler; and means comprising a plurality of valves spaced about said tumbler, springs for holding said valves closed at times, and mechanism for intermittently opening said valves against the action of said springs for intermittently releasing the pressure of steam which is generated within said tumbler during the calcining process; and a portably mounted support for said tumbler, said rotating means, said steam introducing means, said pressure varying means, and said pressure releasing means.

7. A calcining device of the class described comprising a portably mounted platform; a tumbler mounted on said platform for rotation thereon; means mounted on said platform for rotating said tumbler; a plurality of heating pipes in said tumbler; means for introducing steam under pressure into said heating pipes; mear s for withdrawing condensate from said pipes; and means for intermittently releasing the pressure of steam which is generated in said tumbler during the calcining process.

LEWIS C. KARRICK.

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Number	Country	Date
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ITHAN LAND CO.,
Wayne, Pa., September 6, 1952.

Hon. JOHN R. MURDOCK,
Chairman, Committee on Interior and Insular Affairs,
The House Office Building, Washington, D. C.

DEAR MR. MURDOCK: With reference to the discussion several weeks ago in your office between Mr. Soule, Dr. Karrick, yourself and the writer concerning our mutual interest in the promotion of a gypsum industry in Arizona, and specifically as this may relate to Dr. Karrick's patented process for the manufacture of material suitable for low-cost Indian housing, etc.

At Mr. Soule's suggestion, I am enclosing a schematic diagram of a 2-ton portable plant, the details of which plant have already been designed.

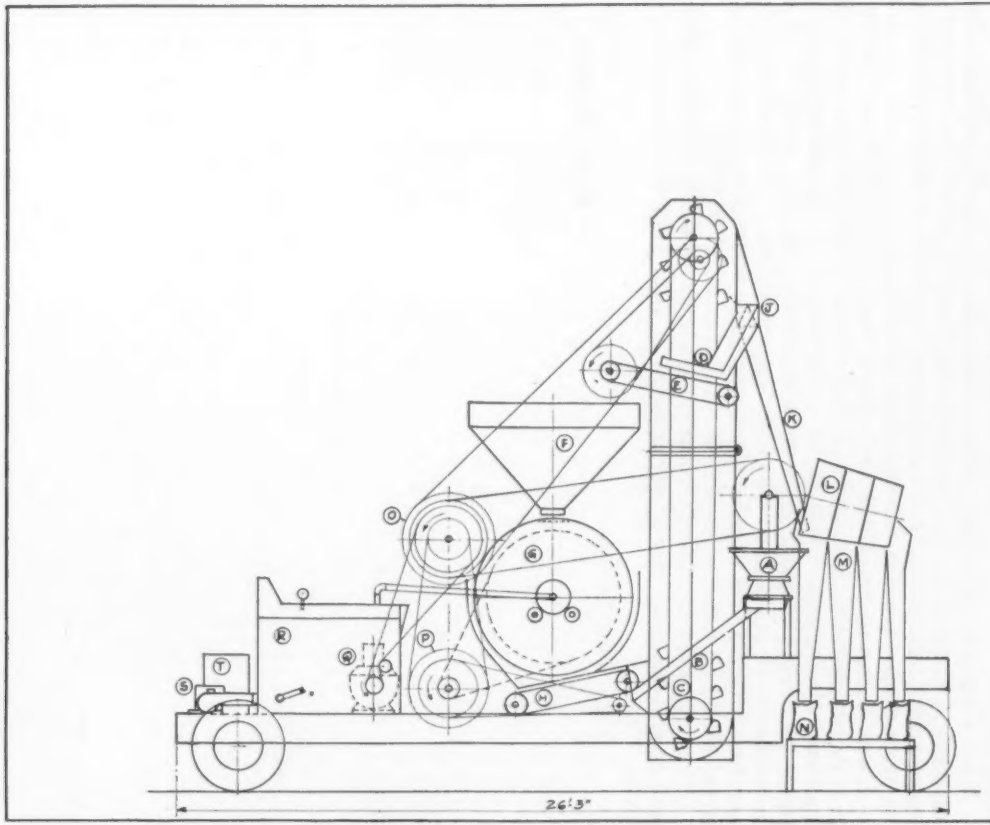
This diagram, with very little study, should clearly indicate the method of processing and handling the material, from the raw-rock stage prior to crushing, to the sacking of the finished product in three or more graded sizes as it comes from the screen.

I would like to point out that this self-contained plant may seem a trifle complicated, but it should be borne in mind that the essential mechanical equipment had to be encompassed in the rather limited space as to width and height on a semitrailer chassis, owing to the restrictions of interstate vehicular transportation. A stationary or semiportable plant of equal capacity, with no limitations as to ground area, would be much more simple and economical to build.

Trusting that this small contribution may assist in serving your cause, and assuring you of my interest in your very deserving enterprise, I am,

Very truly yours,

P. B. ECKELS.


MACHINERY COMPONENTS
(A) CRUSHER
(B) CHUTE TO ELEVATOR BOOT
(C) BUCKET ELEVATOR
(D) DISCHARGE CHUTE TO CONVEYOR
(E) BIN CONVEYOR
(F) 2-TON BIN FOR RAW GYPSUM
(G) 2-TON ROTARY CALCINER
(H) GYPSUM CONVEYOR TO ELEVATOR
(J) GATE IN DISCHARGE CHUTE
(K) CHUTE TO SIZING SCREEN
(L) SCREEN-3 SIZES + OVERSIZE
(M) SCREEN HOPPERS
(N) BAGS ON PLATFORM
(O) LINESHAFT
(P) COUNTER SHAFT
(Q) 20-H.P. GASOLINE ENGINE
(R) 12-H.P. STEAM BOILER
(S) OIL BURNER
(T) FUEL OIL TANK
(U) WATER TANK (NOT SHOWN)
(V) 5 K.W. GENERATOR ON ENGINE
26'3"
SCHEMATIC DIAGRAM OF
PORTABLE
2-TON GYPSUM CALCINER
KARRICK PATENT 2,479,576
ON 10-TON SEMI-TRAILER
DRAWN BY F.B. ECKELS
SCALE - APPX. 3/8" = 1 FOOT
K-19

UNITED STATES DEPARTMENT OF COMMERCE,
NATIONAL BUREAU OF STANDARDS,
Washington, June 30, 1949.

REPORT ON THE COMPRESSIVE STRENGTH OF CALCINED GYPSUM AGGREGATE CONCRETE

I. INTRODUCTION

Samples of gypsum rock from Virginia and from Nova Scotia were crushed, screened, and calcined. The resulting aggregate was placed in molds, wetted and compacted to a cohesive mass.

The calcination converted the outside of the pebbles of rock gypsum to hemihydrate according to the following reaction:

$$\underset{\text{(gypsum)}}{CaSo_4.2H_2O} \xrightarrow{\text{heat}} \underset{\text{(hemihydrate)}}{CaSo_4.\tfrac{1}{2}H_2O} + \underset{\text{(steam)}}{1\tfrac{1}{2}H_2O}$$

The depth of calcination depended upon the time and temperature of calcination and the size of the pebbles. By prolonged calcination the gypsum pebbles were completely converted to hemihydrate. The addition of water to the cooled aggregate converted the hemihydrate back to gypsum according to the reaction:

$$\underset{\text{(hemihydrate)}}{CaSo_4.\tfrac{1}{2}H_2O} + \underset{\text{(water)}}{1\tfrac{1}{2}H_2O} \longrightarrow \underset{\text{(gypsum)}}{CaSo_4.2H_2O}$$

The wetted aggregate was compacted by vibration or pressure soon after wetting. The aggregates were forced into intimate contact, became cemented together, and hardened as the hemihydrate reverted to gypsum. The calcined or partially calcined aggregate furnished its own cementing materials.

The gypsum was furnished by L. C. Karrick who supervised the construction of the test specimens. Mr. Karrick also supervised the information about the preparation of the aggregate that is given in this report.

The specimens were made and tested at this Bureau.

II. AGGREGATE

The gypsum rock from Virginia and from Nova Scotia was crushed and screened. It was calcined at a temperature of 107° to 150° C. for periods of 1, 1½, or 2 hours. The resulting aggregate was in the form of pebbles which passed a one-half inch sieve and was retained on a one-quarter inch (No. 4) sieve. The gradation was said to be as given below.

Gradation of calcined gypsum aggregate

Source of rock	Weight retained on sieve size No.—		
	½-inch, percent	5/16-inch, percent	¼-inch, percent
Virginia	0	70	30
Nova Scotia	0	60	40

Calcination for 2 hours was said to completely change the rock to the hemihydrate ($CaSo_4$ ½ H_2O). Calcination for either 1 or 1½ hours was said to produce a coating of hemihydrate on the outside of the pebbles but left a core of the uncalcined rock in the center of the pieces of aggregate.

The aggregates are designated by letters and numbers indicating the source of the rock and the period of calcination. For example, aggregate V–1, V–1.5, and V–2 were Virginia aggregates calcined for 1, 1½, and 2 hours, respectively. All of the Nova Scotia aggregate designated as N–2 was calcined for 2 hours.

III. SPECIMENS

The specimens included 12 4-inch-diameter cylinders, 3 3½-inch-thick prisms, and a wallette. They were made in the interval between April 1 and April 7, 1949, and were stored in the laboratory until tested. The dimensions of the prism and cylinder specimens, the kind of aggregate used in them, and their age when tested are listed with other data and are given in table 1. The making of the specimens is described below.

1. Prisms

The three prisms were 3.5- by 3.5-inch cross section and were about 7 inches high. They were made of aggregate V–2 and were formed in two equal lifts. Each lift contained 2.25 pounds of dry aggregate. After the aggregate for the first lift was placed in the mold about 0.7 pound of water was poured over it. A loose-fitting square wood block was then placed in the mold over the aggregate and pressure was applied until the height of the aggregate in the mold was reduced by 15 percent. The second and top half of the prism was immediately placed in the same manner. Since the prisms forms were about 7⅝ inches high the finished prism was about 7 inches high. The prisms were designated as P–1, P–2, and P–3.

2. Cylinders

The steel cylinder molds were 4 inches in diameter and 8 inches high. A space of one-eighth inch was left open between the bottom of the cylinder molds and their supporting base to permit the drainage of water from the aggregate. Cylinders C–1 to C–6, inclusive, were cast in two lifts, each containing 2.25 pounds of dry aggregate. After the aggregate for the first lift was placed in the mold, the mold was immersed in water for about 20 seconds and until bubbles ceased to rise from the aggregate. After immersion, water was permitted to drain from the mold for 1 minute when a pressure was applied to the aggregate until its height in the mold was reduced by 15 percent. The second lift for these specimens was placed in a similar manner.

Cylinders C–7 to C–12, inclusive, were compacted in a different manner. About 4.5 pounds of dry aggregate was placed in each mold, the aggregate being heaped up over the top of the mold. The aggregate was then shaken into place, until level with the top of the mold, by placing an electric vibrator in contact with the outside of the mold. The vibrator was of a spud type having a frequency of 14,000 cycles per minute. After the initial vibration, the molds were immersed in water for 20 seconds, removed, and allowed to drain for 1

minute. They were then vibrated for the second time and until the top of the aggregate was depressed in the mold a distance of 0.7 inch below the top of the mold.

3. Wallette

The wallette made of aggregate V–2 was 3½ inches thick, 2- inches long, and 22 inches high. It was built in four major lifts, each lift containing two horizontal layers. The forms were of wood. A space of one-eighth inch was left between the bottom of the form and the lower edges of the side forms used for the first lift to permit the drainage of water from the aggregate. A similar space was left between the successive form boards, each of which was 5½ inches high.

Each lift was placed as follows: The dry aggregate for each of the two layers in a lift weighed 13 pounds. The aggregate for the first layer was leveled in the form and wetted slowly with water from a one-fourth-inch diameter hose. When the aggregate appeared to be thoroughly wetted it was compressed with a lever arrangement applied to a board on the top surface of the aggregate until the depth of the layer was reduced from about 3¼ to 2¾ inches. The second layer was immediately placed in the same manner. After a lift was finished, an interval of 1 hour elapsed before the next lift was started. Approximately 21.2 pounds of water and 104 pounds of V–2 aggregate was used in the wallette.

IV. STRUCTURAL PROPERTIES

The elastic properties of the prisms and cylinders were determined with sonic apparatus at two different ages, the last observations being made 1 day before the specimens were tested to failure in compression. Young's modulus, the rigidity modulus and Poisson's ratio were calculated from determinations of flexural and torsional resonant frequencies of forced vibration.[1] The values of the moduli, Poisson's ratio, and the compressive strength are listed in table 2.

V. CONCLUSIONS

1. The data, table 2, show that specimens of different size or shape made with somewhat differing techniques but containing like aggregates showed a wide dispersion in compressive strength.

2. While it was indicated that the period of calcination affected the compressive strength of the cylinders, it is probable that the method or degree of compaction was also an important factor.

The contents of this report are not to be used for advertising, publication, or promotional purposes.

D. E. Parsons,
Chief, Building Technology Division
(For the Director).

[1] See paper by Gerald Pickett, Proc. A. S. T. M., vol. 45, 1945: reprint 47.

TABLE 1.—*Dimensions and physical properties of prisms and cylinders*

Specimen No.	Kind of aggregate [1]	Dimensions		Dry aggregate used	Water applied	Weight of air-dry specimen per cubic foot of concrete [2]	Date made	Compressive strength tests		
		Diameter or side	Length					Date tested	Age when tested	Weight when tested [3]
		In.	*In.*	*Lbs.*	*Lbs.*	*Lbs.*			*Days*	*Lbs.*
P-1	V-2	3.5	7.0	4.5	1.83	109	Apr. 4, 1949	Apr. 15, 1949	11	5.32
P-2	V-2	3.5	7.0	4.5	1.83	109	do	do	11	5.37
P-3	V-2	3.5	7.0	4.5	1.83	109	do	do	11	5.37
C-1	V-2	4.0	7.5	4.5	.33	107	Apr. 1, 1949	do	14	5.74
C-2	V-2	4.0	7.4	4.5	.33	107	do	do	14	5.69
C-3	V-2	4.0	7.3	4.5	.33	107	do	do	14	5.78
C-4	N-2	4.0	7.4	4.5	1.0	97	Apr. 5, 1949	do	10	5.25
C-5	N-2	4.0	7.5	4.5	1.0	97	do	do	10	5.27
C-6	N-2	4.0	7.5	4.5	1.0	97	do	do	10	5.22
C-7	V-1	4.0	7.5	5.0	.6	100	Apr. 7, 1949	do	8	5.38
C-8	V-1	4.0	7.4	5.0	.6	100	do	do	8	5.31
C-9	V-1	4.0	7.4	5.0	.6	100	do	do	8	5.38
C-10	V-1.5	4.0	7.4	5.0	.8	100	do	do	8	5.37
C-11	V-1.5	4.0	7.4	5.0	.8	100	do	do	8	5.37
C-12	V-1.5	4.0	7.5	5.0	.8	100	do	do	8	5.42

[1] Designation of aggregate. The letters indicate source of rock, V, Virginia; N, Nova Scotia. The numerals indicate time of calcination in hours.
[2] Average weight for each group of specimens.
[3] Weight when air dry.

TABLE 2.—*Structural properties*

Specimen	Kind of aggregate	Young's modulus of elasticity E				Rigidity modulus—Initial observation		G—Final observation		Poisson's ratio ν				Compressive strength	
		Initial observation		Final observation						Initial observation		Final observation			
		Age of specimen	Value of $\frac{E}{10^6}$	Age of specimen	Value of $\frac{E}{10^6}$	Age of specimen	Value of $\frac{G}{10^6}$	Age of specimen	Value of $\frac{G}{10^6}$	Age of specimen	ν	Age of specimen	ν	Age of specimen	Strength
		Days	*Lb./in.²*	*Days*	*Lb./in.²*	*Days*	*Lb./in.²*	*Days*	*Lb./in.²*	*Days*		*Days*		*Days*	*Lb./in.²*
P-1	V-2	1	0.96	10	0.92	1	0.38	10	0.41	1	0.26	10	0.13	11	650
P-2	V-2	1	1.09	10	1.10	1	.45	10	.49	1	.22	10	.12	11	870
P-3	V-2	1	1.04	10	1.04	1	.39	10	.42	1	.32	10	.23	11	810
Average		1	1.03	10	1.02	1	.41	10	.44	1	.27	10	.16	11	780
C-1	V-2	3	1.15	13	1.24	3	.51	13	.57	3	.13	13	.09	14	1,000
C-2	V-2	3	1.51	13	1.64	3	.65	13	.70	3	.17	13	.17	14	1,170
C-3	V-2	3	1.69	13	1.80	3	.76	13	.83	3	.12	13	.09	14	1,310
Average		3	1.45	13	1.56	3	.64	13	.70	3	.14	13	.12	14	1,160
C-4	N-2	1	1.41	9	1.24	1	.54	9	.50	1	.32	9	.24	10	1,040
C-5	N-2	1	1.28	9	1.16	1	.48	9	.48	1	.33	9	.20	10	1,010
C-6	N-2	1	1.14	9	.99	1	.43	9	.42	1	.33	9	.15	10	800
Average		1	1.28	9	1.13	1	.48	9	.47	1	.33	9	.20	10	950
C-7	V-1	4	1.00	7	.95	4	.44	7	.44	4	.15	7	.09	8	480
C-8	V-1	4	1.02	7	1.02	4	.47	7	.47	4	.10	7	.10	8	520
C-9	V-1	4	1.07	7	1.07	4	.45	7	.45	4	.18	7	.19	8	590
Average		4	1.03	7	1.01	4	.45	7	.45	4	.14	7	.13	8	530
C-10	V-1.5	4	1.16	7	1.27	4	.54	7	.53	4	.08	7	.19	8	720
C-11	V-1.5	4	1.25	7	1.29	4	.55	7	.55	4	.14	7	.17	8	730
C-12	V-1.5	4	1.36	7	1.38	4	.58	7	.58	4	.17	7	.19	8	690
Average		4	1.26	7	1.31	4	.56	7	.55	4	.13	7	.18	8	710
Wallette	V-2													14	360

COMMITTEE NOTE.—The abbreviation "Lb./in.²" means "pounds per square inch."

DEPARTMENT OF COMMERCE,
NATIONAL BUREAU OF STANDARDS,
Washington 25, September 8, 1952.

Subject: Compressive Strength of Masonry Walls.

Hon. JOHN R. MURDOCK,
Chairman, Committee on Interior and Insular Affairs,
House of Representatives, Washington, D. C.

DEAR MR. MURDOCK: This letter is being sent to you at the request of Mr. George H. Soule, Jr., technical consultant on mining and minerals. Mr. Soule requested information regarding the compressive strength of masonry walls in his letter of September 3.

The compressive strength of brick masonry varies considerably and is influenced primarily by the compressive strength of the individual units, the compressive strength of the mortar, and the quality of workmanship. It will therefore be necessary to qualify the information requested in your letter by describing the masonry unit, the mortar, and the workmanship.

The data on the compressive strengths of masonry walls are given below:

Average compressive strength of brick walls

Kind of brick	Compressive strength of brick	Average compressive strength of solid walls	
		Cement-lime mortar	Cement mortar
	Lb./in.²	*Lb./in.²*	*Lb./in.²*
Chicago	3,280		895
Detroit	3,540	945	1,145
Mississippi	3,410	1,300	1,550
New England	8,600	1,875	2,855

COMMITTEE NOTE.—The abbreviation "Lb./in.²" means "pounds per square inch."

These data were obtained with brick walls having completely filled vertical joints and smoothly spread horizontal mortar beds. The source of these data is Research Paper 108 published in the Journal of Research of the National Bureau of Standards, volume 3, October 1929.

In regard to the compressive strengths of concrete masonry walls, the data given in the paper entitled "Tests of Stability of Concrete Masonry Walls," Proceedings of ASTM, volume 31, 1931, may be cited. The authors state that the compressive strengths of large walls of all types varied from 335 to 850 pounds per square inch, and that the strength of walls was dependent mainly upon the strength of the building units and was little affected by variations in the strength of mortar. These conclusions apply to both the "cinder" and "cement" blocks mentioned in your letter.

In regard to allowable stresses in masonry, you are referred to the American Standard Building Code Requirements for Masonry, a copy of which is enclosed. The table given on page 8 of this code, based largely on the results of R. P. 108, gives the permissible compressive stresses in brick masonry for four types of mortar. Similarly, the

permissible stresses in walls of hollow masonry units are given in the second table on page 9 of the code.

I trust that this information may prove helpful to you.

Very truly yours,

A. V. ASTIN, *Director.*

Enclosure.

AMERICAN STANDARD CODE REQUIREMENTS FOR MASONRY

National Bureau of Standards Miscellaneous Publication M 174; Issued March 15, 1944 (out of print)—Extracts from

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SECTION 1. GENERAL

1–1. Application of Requirements

(*a*) Masonry, as defined in this standard, when used in any building or structure shall conform to these requirements.

(*b*) A material other than one of those specifically named in the definition of masonry, which is incombustible and otherwise sufficiently embodies the characteristics of one of the materials named, and which satisfies the requirements for that material, may be classed by the building official with that material which it most closely resembles.

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SECTION 2. MATERIALS

2–1. Solid Masonry Units (Clay or Shale)

(*a*) Brick subject to the action of weather or soil, but not subject to frost action when permeated with water, shall conform to the requirements for grade MW brick of the Tentative Specifications for Building Brick (made from clay or shale), ASTM C 62–41 T. When not subject to the action of weather or soil, brick shall conform to the requirements for grade NW brick.

NOTE.—Grade SW of the above specification should be required where brick may be subject to temperature below freezing while permeated with water.

In localities where brick conforming in physical properties to the requirements of this specification is not readily obtainable, the use of other brick should be permitted if suitable evidence of resistance to weathering is presented to building official.

(*b*) Other solid masonry units of clay or shale shall meet the requirements for physical properties of brick as specified in Section 2–1. (*a*).

2–2. Sand-Lime Brick

Sand-lime brick subject to the action of weather or soil, but not subject to frost action when permeated with water shall conform to the requirements for grade MW brick of the American Standard Specifications for Sand-Lime Building Brick, ASA A78.1–1942 (ASTM C 73–39). When not subject to the action of weather or soil, sand-lime brick shall conform to the requirements for grade NW brick.

NOTE.—Grade SW of the above specification should be required where brick may be subject to temperature below freezing while permeated with water.

2–3. Concrete Brick

Concrete brick subject to the action of weather or soil shall conform to the requirements for grade A brick of the American Standard Specifications for Concrete Building Brick, ASA A75.1–1942 (ASTM C 55–37). When not subject to the action of weather or soil, concrete brick shall conform to the requirements for grade B brick.

2–4. Structural Clay Tile

(*a*) Structural clay tile subject to the action of weather or soil shall conform to the requirements for grade LBX tile of the American Standard Specifications for Structural Clay Load-Bearing Wall Tile, ASA A74.1–1942 (ASTM C 34–41).

(*b*) Structural clay tile used in load-bearing masonry but not subject to the action of weather or soil shall conform to the requirements for grade LB tile of the above specification.

(*c*) Structural clay tile used in interior non-load-bearing masonry shall conform to the requirements of the American Standard Specifications for Structural Clay Non-Load-Bearing Tile, ASA A76.1–1942 (ASTM C 56–41).

2–5. Concrete Masonry Units

(*a*) Hollow concrete masonry units used in load-bearing masonry or subject to the action of weather or soil shall conform to the requirements of the American Standard Specifications for Hollow Load-Bearing Concrete Masonry Units, ASA A79.1–1942 (ASTM C 90–39).

(*b*) Hollow concrete masonry units used in non-load-bearing masonry not subject to the action of weather or soil shall conform to the requirements of the American Standard Specifications for Hollow Non-Load-Bearing Concrete Masonry Units, ASA A80.1–1942 (ASTM C 129–39).

(*c*) Solid concrete masonry units shall conform to the requirements of the American Standard Specifications for Solid Load-Bearing Concrete Masonry Units, ASA A81.1–1942 (ASTM C 145–40).

2–6. Plain Concrete

(*a*) Cast-in-place concrete construction, reinforced only for shrinkage or temperature changes shall be classed as plain concrete. Plain concrete other than concrete fill shall have a minimum compressive strength at 28 days of 2,000 psi.

(*b*) Portland cement shall conform to the requirements of the Standard Specifications for Portland Cement, ASTM C 150–42.

(*c*) Natural cement shall conform to the requirements of the Standard Specifications for Natural Cement, ASTM C 10–37.

(*d*) Concrete aggregates shall conform to the requirements of the Standard Specifications for Concrete Aggregates, ASTM C 33–42. The maximum size of the aggregates shall not exceed one-fifth of the narrowest dimension between forms of the member for which the concrete is to be used, nor 2½ inches.

(*e*) Water used in mixing concrete shall be clean, and free from deleterious amounts of acids, alkalis, or organic materials.

NOTE.—Water suitable for drinking purposes is satisfactory.

2–7. Cast Stone

Cast stone shall conform to the requirements of the Specification for Cast Stone, ACI 704–44.

2–8. Natural Stone

Stone for masonry shall be sound and free from loose or friable inclusions. It shall have sufficient strength, durability, and resistance to impact for the proposed use.

2–9. Architectural Terra Cotta

Architectural terra cotta shall have a strong homogeneous body and give a sharp metallic, bell-like ring when struck. All units shall have the necessary anchor holes and shall be so formed as to engage properly with the supporting structure.

2–10. Glazed Building Units

Glazed building units shall conform to the requirements of the Tentative Specifications for Glazed Building Units ASTM C 126–39 T except that the requirements for finish shall not apply to salt-glazed building units.

2–11. Gypsum Tile and Block

(*a*) Gypsum partition tile or block shall conform to the requirements of the Standard Specifications for Gypsum Partition Tile or Block, ASTM C 52–41.

(*b*) Gypsum partition tile or block shall not be used in bearing walls or in exterior walls, or where subject to continuous dampness.

2–12. Structural Glass Block

Glass blocks may be solid or hollow. All mortar bearing surfaces of the blocks shall be precoated with a material to improve adhesion between mortar and glass.

2–13. Mortar Materials

(*a*) Cementitious materials used in mortars shall conform to the requirements of the following applicable standard specifications:

Quicklime for Structural Purposes, ASTM C 5–26.
Hydrated Lime for Structural Purposes, ASTM C 6–31.
Hydraulic Hydrated Lime for Structural Purposes, ASTM C 141–42.
Natural Cement, ASTM C 10–37.
Masonry Cement, Federal Specification SS–C–181b.
Portland Cement, ASTM C 150–42.

(*b*) Aggregate for mortar shall conform to the requirements of the Tentative Specifications for Aggregate for Masonry Mortar, ASTM C 144–42 T.

NOTE.—Materials which have been found in practice to cause harmful volume changes should not be incorporated in masonry.

(*c*) Water used in mixing mortar shall be clean, and free from deleterious amounts of acids, alkalis, or organic materials.

NOTE.—Water suitable for drinking purposes is satisfactory.

2–14. Mortar Requirements

(*a*) Mortar as delivered to the mason shall have a flow after suction for 1 minute of not less than 65 percent of that immediately before suction. The flow shall be determined by the method of the Water Retention Test of the Federal Specification for Masonry Cement, SS–C–181b.

(*b*) The volume of aggregate in mortar shall be at least two times but not more than three times the volume of cementitious material.

2–15. Classification of Mortar

(*a*) Mortar used in masonry construction shall be classified as follows:

Minimum compressive strength of 2-inch cubes at 28 days

Type—	Psi
A	2, 500
B	600
C	200
D	75

(*b*) Unless the strength classification of the mortar has been otherwise established by test as prescribed in section 2–15 (*c*), mortars of the following proportions, with the aggregate measured in a damp and loose condition, may be assumed to meet the strength classification given in section 2–15 (*a*).

Proportions by volume

Mortar type	Cement	Hydrated lime or lime putty allowable range	Aggregate measured in a damp and loose condition
A	1 (portland)	0 to ¼	Not more than 3.
B	1 (portland)	1 to 1¼	Not more than 6.
B	1 (masonry FS type II)		Not more than 3.
C	1 (portland)	2 to 2½	Not more than 9.
C	1 (masonry FS type I)		Not more than 3.
D	0 to ½ (portland)	1 to 1¼	Not more than 3 parts for each part of cementitious material.

NOTE.—The weights per cubic foot of the materials in mortar are to be considered as follows:

Portland cement	94 pounds.
Masonry cement	Weight printed on bag.
Hydrated lime	40 pounds.
Sand, damp and loose	1 cubic foot contains 80 pounds of dry sand.

(*c*) Mortar of materials conforming to the requirements of Section 2–13, and of any proportions conforming to Section 2–14 (b), may qualify as mortar of any one of four types, provided it conforms to the physical requirements of Sections 2–14 (a) and 2–15 (a).

When it is desired to establish the strength classification of a given mortar by test, the strength shall be determined with mortar prepared in a testing laboratory, of representative materials and in the proportions proposed for use. The test cubes shall be molded, cured, and tested for compressive strength as described in the Federal Specification for Masonry Cement, SS–C–181b, except that for type D mortar the entire curing shall be in laboratory air at 70° F 5°.

2–16. Types of Mortars Required

Masonry shall be laid in type A, type B, or type C mortar, except as follows:

(*a*) Type A mortar shall be used in nominal 10-inch cavity walls, foundations walls of hollow masonry units, and masonry linings of existing masonry walls.

(*b*) Type A or type B mortar shall be used in footings, foundation walls of solid masonry units, isolated piers, load-bearing or exterior walls of hollow masonry units, hollow walls of masonry, and cavity walls exceeding nominal 10-inch thickness.

(*c*) Type D mortar may be used in solid masonry walls, other than parapet walls or rubble stone walls, not in contact with the soil and not less than 12 inches thick nor more than 35 feet in height, provided the walls are laterally supported at intervals not exceeding 12 times the wall thickness.

(*d*) Gypsum partition tile and block shall be laid in gypsum mortar. Nonbearing partitions and fireproofing of structural clay tile may be laid in gypsum mortar. Fire brick shall be laid in fire clay or air-setting mortar.

(*e*) Glass block when laid in mortar shall be laid in type B mortar.

SECTION 3. ALLOWABLE STRESSES IN MASONRY

3–1. General

(*a*) Every building or structure hereafter erected and all new construction in the alteration of an existing building or structure shall be so designed and constructed that the working stresses prescribed in this section are not exceeded. In using these stresses, the effects of all loads and conditions of loading and the influence of all forces affecting the design and strength of the several parts shall be taken into account.

(*b*) Higher stresses than herein specified may be used, but only if it is clearly established to the satisfaction of the building official, by test or other satisfactory evidence, that material of a higher grade or a superior workmanship than is generally provided in accepted good practice is to be employed under approved inspection. The use of higher stresses, however, shall not be allowed until a statement, giving the reasons for such permission, together with the facts and circumstances on which it is based, is placed on file and made a part of the official record of the permit.

3–2. Composite Walls

In walls or other structural members composed of different kinds or grades of units or mortar, the maximum stress shall not exceed the allowable stress for the weakest of the combinations of units and mortars of which the member is composed.

3–3. Solid Masonry Units

The allowable compressive stresses in pounds per square inch of gross cross-sectional area in solid masonry of solid units shall not exceed the following limits:

Brick and other solid units of clay or shale; sand-lime or concrete brick

Average compressive strength of units tested in the position taken in the masonry	Mortar type			
	A	B	C	D
Psi	*Psi*	*Psi*	*Psi*	*Psi*
8,000-plus	400	300	200	100
4,500 to 8,000	250	200	150	100
2,500 to 4,500	175	140	110	75
1,500 to 2,500	125	100	75	50

NOTE.—For allowable stresses in hollow walls of solid units and in cavity walls, see sec. 9, cavity walls and hollow walls of solid units.

Solid concrete-masonry units

Grade	Mortar type		
	A	B	C
	Psi	*Psi*	*Psi*
A	175	125	80
B	125	100	60

3–4. Hollow Masonry Units

The allowable compressive stresses in pounds per square inch of gross cross-sectional area in masonry of hollow units of structural clay tile or of hollow concrete masonry units shall not exceed the following limits:

Unit	Mortar type	
	A	B
	Psi	*Psi*
Hollow units	85	70

3–5. Plain Concrete

The allowable stresses shall not exceed 25 percent for compression, and 3 percent for tension in extreme fiber in flexure, of the compressive strength of the concrete. When the ratio of height to thickness of structural members of plain concrete exceeds 10, the above percentage for compression shall be reduced proportionately to 18 percent for a ratio of height to thickness of 20.

3–6. Stone and Cast Stone

The allowable stresses in compression, in pounds per square inch of gross cross-sectional area shall not exceed the following limits:

Material	Mortar			
	A	B	C	D
	Psi	*Psi*	*Psi*	*Psi*
Granite, ashlar	800	640	500	400
Limestone, ashlar	500	400	325	250
Marble, ashlar	500	400	325	250
Sandstone, ashlar	400	320	250	160
Cast stone	400	320	250	160
Rubble stone	140	100	80	----------

SECTION 4. LATERAL SUPPORT

4–1. Solid masonry walls, shall be supported at right angles to the wall face at intervals not exceeding 20 times the nominal wall thickness if laid in type A, B, or C mortar, and not exceeding 12 times the nominal wall thickness if laid in type D mortar.

4–2. Walls of structural clay tile or hollow concrete masonry units, and hollow walls of masonry shall be supported at right angles to the wall face at intervals not exceeding 18 times the nominal wall thickness.

4–3. Cavity walls shall be supported at right angles to the wall face at intervals not exceeding 14 times the nominal wall thickness.

4–4. Lateral support may be obtained by cross walls, piers, or buttresses, when the limiting distance is measured horizontally, or by floors and roofs when the limiting distance is measured vertically. Sufficient bonding or anchorage shall be provided between the walls and the supports to resist the assumed wind force, acting either inward or outward. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transfer the wind force, acting in either direction, to the ground. When walls are dependent upon floors or roofs for their lateral support, provision shall be made in the building to transfer the lateral forces to the ground.

4–5. Except for window-paneled backs, and permissible chases and recesses, walls shall not vary in thickness between their lateral supports. When a change in thickness, due to minimum thickness requirements, occurs between floor levels, the greater thickness shall be carried up to the higher floor level.

SECTION 5. SOLID MASONRY WALLS

5–1. Thickness of Solid Masonry Bearing Walls

(*a*) The thickness of solid masonry bearing walls shall be sufficient at all points to keep the combined stresses due to live, dead, and other loads for which the building is designed within the limits prescribed by Section 3, Allowable Stresses in Masonry.

(*b*) Except as otherwise provided in this section, the minimum nominal thickness of solid masonry bearing walls shall be 12 inches for the uppermost 35 feet of their height, and shall be increased 4 inches for each successive 35 feet or fraction thereof, measured downward from the top of the wall.

(*c*) Where solid masonry bearing walls are stiffened at distances not greater than 12 feet apart by cross walls, or by internal or external offsets or returns at least 2 feet deep, or by reinforced concrete floors, they may be of 12-inch nominal thickness for the uppermost 70 feet, measured downward from the top of the wall, and shall be increased 4 inches in thickness for each successive 70 feet or fraction thereof.

(*d*) In buildings not more than three stories in height, solid masonry bearing walls of the top story may be of 8-inch nominal thickness when the total height of the wall does not exceed 35 feet, provided that such 8-inch walls do not exceed 12 feet in height and that the roof beams are horizontal.

(*e*) In residential buildings not more than three stories in height, solid masonry bearing walls may be of 8-inch nominal thickness when not over 35 feet in height. Such walls in one-story single-family dwellings, and 1-story private garages, may be of 6-inch nominal thickness when not over 9 feet in height, provided that when gable construction is used an additional 6 feet is permitted to the peak of the gable.

(*f*) Solid masonry walls above roof level, 12 feet or less in height, enclosing stairways, elevator shafts, penthouses, or bulkheads may be of 8-inch nominal thickness and may be considered as neither increasing the height nor requiring any increase in the thickness of the wall below, provided the requirements for allowable stresses are met.

NOTE.—For requirements for lateral support, see Section 4, Lateral Support; for hollow walls, see Section 9, Cavity Walls and Hollow Walls of Solid Units; for veneered walls, see Section 10, Veneered Walls; for faced walls, see Section 11, Faced Walls.

5–2. Thickness of Solid Masonry Nonbearing Walls

Nonbearing walls of solid masonry may be 4 inches less in thickness than required for bearing walls, but the nominal thickness shall be not less than 8 inches except where 6-inch walls are specifically permitted.

NOTE.—For requirements for lateral support, see Section 4, Lateral Support.

5–3. Bond

The facing and backing of solid masonry walls shall be bonded either with at least one full header course in each seven courses, or with at least one full-length header in each 1.5 square feet of wall surface. The distance between adjacent full-length headers shall not exceed 20 inches either vertically or horizontally. In solid brick walls of more than 8-inch nominal thickness, the inner joints of header courses shall be covered with another header course which shall break joints with the course below.

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SECTION 9. CAVITY WALLS AND HOLLOW WALLS OF SOLID UNITS

9–1. Allowable Stresses

In cavity walls and in hollow walls of solid masonry units, the compressive stresses in psi of gross cross-sectional area shall not exceed the following:

	Psi
Solid masonry units with mortar A	125
Solid masonry units with mortar B	100
Hollow masonry units with mortar A	60
Hollow masonry units with mortar B	50
Plain concrete	300

NOTE.—See Section 3–2 for composite walls and Section 2–16 for types of mortar permitted in cavity walls.

9–2. Height

Except as otherwise limited by Section 9–3 (a), cavity walls and hollow walls of solid masonry units shall not exceed 35 feet in height.

9–3. Thickness

(*a*) Cavity walls and hollow walls of solid masonry units shall be not less in thickness than required for solid masonry walls in Section 5, Solid Masonry Walls, provided that 10-inch cavity walls shall not exceed 25 feet in height.

(*b*) In cavity walls neither the facing nor backing shall be less than 3¾ inches in nominal thickness, and the cavity shall be not less than 2 inches nor more than 3 inches in width.

NOTE.—For requirements for lateral support, see Section 4, Lateral Support.

9–4. Bond

(*a*) In hollow walls of solid masonry units, the facing and backing shall be securely tied together with headers or bonding units, as required for solid masonry walls in Section 5–3 so that the parts of the wall will exert common action under the load.

(*b*) Where such walls are decreased in thickness, a course of solid masonry shall be interposed between the wall below and the thinner wall above.

(*c*) In cavity walls the facing and backing shall be securely tied together with suitable bonding ties of adequate strength. A steel rod $\frac{3}{16}$ inch in diameter or a metal tie of equivalent stiffness coated with a noncorroding metal or other approved protective coating shall be used for each 3 square feet of wall surface. Where hollow masonry units are laid with the cells vertical, rectangular ties shall be used; in other walls the ends of ties shall be bent to 90-degree angles to provide hooks not less than 2 inches long. Ties shall be embedded in horizontal joints of the facing and backing. Additional bonding ties shall be provided at all openings, spaced not more than 3 feet apart around the perimeter and within 12 inches of the opening. Cavity walls of plain concrete shall be reinforced as provided in Section 7, Solid Walls of Plain Concrete.

9–5. Drainage

In cavity walls the cavity shall be kept clear of mortar droppings during construction. Approved flashing shall be installed and adequate drainage provided to keep dampness away from the backing.

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SECTION 12. FOUNDATION WALLS

12–1. Foundation walls shall be of sufficient strength and thickness to resist lateral pressures from adjacent earth and to support their vertical loads without exceeding the stresses specified in Section 3, Allowable Stresses in Masonry; provided, that in no case shall their thickness be less than the walls immediately above them, except as provided in Section 12–3.

12–2. Foundation walls shall be of not less than 12-inch nominal minimum thickness, except as follows:

(*a*) Solid masonry walls reinforced with at least one $\frac{3}{8}$-inch round deformed bar, continuous from footing to top of foundation wall, for each 2 feet of length of the wall, may be of 8-inch nominal thickness.

(*b*) Solid foundation walls of solid masonry units or of coursed stone that do not extend more than 5 feet below the adjacent finished ground level, and hollow walls of masonry and walls of hollow units that do not extend more than 4 feet below the adjacent finished ground level, may be 8 inches in nominal minimum thickness. These depths may be increased to a maximum of 7 feet with the approval of the building official when he is satisfied that soil conditions warrant such increase. The total height of the foundation wall and the wall supported shall not exceed that permitted by these requirements for 8-inch walls.

(*c*) Foundation walls of rubble stone shall be at least 16 inches thick. Rough or random rubble without bonding or level beds shall not be used as foundations for walls exceeding 35 feet in height, nor shall coursed bonded rubble walls be used as foundations for walls exceeding 50 feet in height.

(*d*) Foundation walls of cast-in-place concrete shall be at least 8 inches thick; provided that when supporting one-story structures, and the area within the foundation walls is not excavated, they may be 6 inches thick if the total height of the foundation wall and the wall supported is within the allowable height of 6-inch walls.

12–3. Foundation walls of 8-inch nominal thickness and conforming to the provisions of this section may be used as foundations for single-

family dwellings with walls of brick veneer on frame walls, or with nominal 10-inch cavity walls, provided that the dwelling is not more than 1½ stories in height and the total height of the wall, including the gable, is not more than 20 feet. Foundation walls of 8-inch nominal thickness supporting brick veneer or cavity walls shall be corbelled with solid units to provide a bearing the full thickness of the wall above. The total projection shall not exceed 2 inches with individual corbels projecting not more than one-third the height of the unit. The top corbel course shall be not higher than the bottom of floor joists and shall be a full header course.

12–4. Foundation walls shall extend below the level of frost action.

Gypsum—Properties, Definitions, and Uses

National Bureau of Standards Circular No. 108, January 3, 1921

(Out of Print)—Extracts from

1. INTRODUCTION

The present generation has seen the rapid development of the gypsum industry to a place of permanence and importance in the building trade. Plaster of Paris and hard wall plaster are gypsum products with which the public is quite familiar, and many new uses for gypsum products, other than as a building material, have been discovered. Gypsum has several valuable properties which are not possessed by any other material. It is therefore adapted to a large variety of uses, not all of which have as yet been commercially developed. In order to take advantage of this opportunity for the expansion of the industry, it is well first to have a knowledge of the different kinds of gypsum products now on the market. Particularly should their names be studied, for the rapid growth of the industry has brought about a confusion of trade terms, which very possibly affects the consumption of the materials. There is a natural reticence about buying or using a material the name of which is not thoroughly established and understood. An explanation of the nomenclature in present use may have the further function of helping to establish definite meanings for the terms.

2. GYPSUM

(a) Occurrence and properties

Gypsum is a rock, which usually occurs bedded in the ground in the same way as limestone or any other of our sedimentary rocks. Pure gypsum is pure white in color and has a translucent sheen. It is apt, however, to be colored by small amounts of certain impurities, particularly iron. Its most distinguishing characteristic is its extreme softness, for it can be readily scratched with a penknife. Not all gypsum is bedded. Sometimes it occurs in pockets or even as boulders distributed through a magma of clay or limestone. A variety of gypsum, which may be regarded as highly consolidated, so that the crystals have disappeared and the mass has become translucent, is known as alabaster. Gypsite is another variety, which has not been consolidated, but occurs in loose form, frequently mixed with con-

siderable amounts of dirt. Gypsite, gypsum, and alabaster bear a relation to each other which is analogous to the relation between marl, limestone, and marble.

Gypsum is a very common mineral. Large deposits of it occur in many localities throughout the United States. It is mined chiefly in New York, Iowa, Michigan, Ohio, and Texas. Many other States produce smaller amounts, and there are a number of known deposits which have not yet been commercially developed. A large part of the gypsum used on the Atlantic seaboard is mined in Nova Scotia. Gypsite is mined in Kansas and Oklahoma. Alabaster is not produced in the United States.

Chemically, gypsum is a hydrated sulphate of calcium. The lime and the sulphuric acid are combined in exact equivalents, so that the product is neither acid nor basic, but neutral. The pure material consists, approximately, of 32.6 percent lime, 46.5 percent sulphuric anhydride, and 20.9 percent water. Anhydrite is another material which is of similar, but not identical, composition and which is frequently found associated with gypsum. It is simply calcium sulphate without any water.

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3. CALCINED GYPSUM

Most gypsum is calcined before it is put on the market. The process of calcination may be defined as the heating of the gypsum under definite conditions to produce a definite material.

(*a*) *Manufacture*

The raw gypsum is first crushed, then dried if necessary, and finally ground to a fine powder before it is fed into the calcining kettles. These kettles are aptly described by their name. They are made of iron, and come in various sizes, holding from 2 to 20 tons. Each kettle is provided with a paddle which rotates on a vertical shaft and keeps the mass stired up. The kettle is set in brickwork and heated by direct fire. A few rotary calciners now in use. These are quite similar to the rotary kilns used in making Portland cement and lime. If a rotary calciner is used, the gypsum is crushed to about three-fourths inch before calcination, but is not finely ground until afterwards; otherwise there would be too much dust carried up the stack.

It was noted above that pure gypsum contains about 20.9 percent water. This water is held in chemical combination, so that the material is normally dry, but the water can be driven off by heat. As the steam escapes from the kettle, it tends to carry the powered gypsum up with it. The whole mass fluffs up and appears to boil. Eventually this violent action ceases, and the mass settles down in the kettle to about its original volume. The material in the kettle at this point is known as "calcined gypsum," sometimes called "first-settle stucco."

(*b*) *Properties*

"Calcined gypsum," then, is gypsum from which part of the water has been removed by heat. Theoretically, this water is given off at 107° C. Practically a slightly higher temperature is used. It takes about an hour to calcine a kettle full of gypsum to "first settle." The chemical reaction involved is: $2(CaSO_4.2H_2O)+\text{heat}=2CaSO_4.H_2O+$

$3H_3O$. Calcined gypsum is therefore $2CaSO_4.H_2O$, or, as it is more usually written, $CaSO_4.\frac{1}{2}H_2O$. From this formula it is frequently called the "hemihydrate." Calcination reduces the water content from 20.9 percent to 6.2 percent and the proportions of the lime and sulphuric anhydride are thereby raised to 38.6 percent and 55.2 percent, respectively.

Calcined gypsum has many peculiar and valuable properties. When mixed with water to form a plastic mass, it sets or hardens. This set can be easily regulated to take place in any desired time. The setting is accompanied by expansion, which property is of great value in making casts or molds. The set material is nearly as strong as Portland cement, and yet is soft enough so that it can be readily tooled. Its porosity and consequent ability to absorb water is important when it is used for making pottery molds. Its ability to set before it dries is the property which makes it valuable as a gaging plaster.

(*c*) *Commercial forms and uses*

Calcined gypsum is probably best known to the general public as "plaster of Paris," but it is sold under a great variety of names, depending upon the purpose for which it is to be used. Thus "dental plaster" is used for making the plaster decorations with which ceilings and walls are sometimes embellished. If the material is used in making plaster casts, statuary, etc., it is called "casting plaster." Under the name of "potters' plaster" it is used for making molds in which terra-cotta, porcelain vases, and other clay products are molded. It is used by the plasterer to mix with lime putty for the "white coat" of plaster, in which case it is called "gaging plaster." All of these materials are essentially calcined gypsum, differing from each other chiefly in the extent to which the time of set has been regulated.

It is unfortunate that such a confusion of nomenclature has come into common use. This is particularly true because there is a tendency now to acknowledge that all of the above names are incorrect. The word "stucco" has been defined by architects and builders to mean a material which is applied in a plastic condition to form that surface of a wall which is exposed to the weather, and which will harden or "set" on exposure. This definition is in contradistinction to the word "plaster," which is the same kind of material, but which is used only on interior walls and ceilings. The material which the gypsum man calls stucco could never be used to make stucco in the way in which the architect understands the word. Nor is the material in any sense a plaster except possibly that small amount of it which is used as gaging plaster. The gypsum manufacturers have been broad enough to see this difficulty and to adopt severe means to meet it. They have decided to drop all of the names above, and to call this material simply "calcined gypsum." Such action is worthy of commendation and support. Of course, such radical changes cannot be brought about by legislation, so that it is hardly likely that this generation will be able to declare the old terms obsolete.

Many of the minor uses of calcined gypsum have been designated above in the paragraph on nomenclature. Next in commercial importance to its structural uses is its use as a retarder for Portland cement. For this purpose, however, much more gypsum is sold raw than calcined. In the manufacture of plate glass, the glass is bedded

in gypsum to hold it while grinding the surface. Calsomine, or cold-water paint, is a mixture of calcined gypsum and specially prepared glue, with or without pigments.

4. HARDENING OF CALCINED GYPSUM

When calcined gypsum sets, it first dissolves in the mixing water. It then combines with the same amount of water that was driven off during the calcination process, and thereby forms a compound which is identical with raw gypsum rock. This raw gypsum, being less soluble than the calcined form, crystallizes out of solution, the crystals interlocking with each other and giving strength to the mass. Since it requires heat to calcine gypsum, it follows that the change back from the calcined to the original form is accompanied by an evolution of heat.

The normal time of set is from 5 to 10 minutes; that is, the mass will become hard in 5 or 10 minutes after the calcined gypsum is mixed with the water. The final setting may be hastened by any means which will aid crystallization. Usually acceleration is accomplished by adding a few crystals of set gypsum to the material. These form nuclei for the crystallization of the rest of the mass, and thereby hasten the reaction. Dental plasters are frequently accelerated so that they will set in one or two minutes. Conversely, any material which tends to prevent crystallization will retard the final setting. It has been found that colloidal substances are very effective for this purpose. The retarder generally used is a byproduct of the tanning industry, similar to glue. Some ready-mixed wall plasters are retarded to set in not less than 6 hours.

Evidently, the time of set of calcined gypsum can easily be controlled to suit the purpose for which it is to be used. This is a distinctive property of this material, and a very valuable one. Accelerators and retarders apparently have little effect on the rate of setting; they merely change the time at which the reaction begins. Judging from the evolution of heat, the reaction in all cases seems to be complete in about half an hour from the time it begins. After the crystallization is complete, further time cannot be expected to show further change. Maximum strength is developed immediately upon the completion of the set. Of course, freshly set gypsum contains a great deal of excess water, and, in common with all similar materials, it is weak on this account. Drying may be accomplished quickly, however, so that an object made of gypsum can be brought to its final strength and condition in a few hours after the calcined gypsum is mixed with water. It is particularly to be noted that this setting does not depend upon exposure; the mixing water furnishes the only ingredient necessary for its completion.

The compressive strength of a good sample of set gypsum (when tested in the form of a cylinder 2 inches in diameter by 4 inches high) is about 2,000 pounds per square inch. Its tensile strength is about 400 pounds per square inch. The age of the specimen makes no difference, provided only that it has had time to set completely, and that it is dry. The quantity of water used for mixing the calcined gypsum does decidedly affect the strength of the set material. Use as little water as possible and still have the mixture workable.

5. GYPSUM WALL PLASTERS

About three-fourths of all the gypsum mined finds its final market as wall plaster. The simplest form of gypsum sold for this purpose is the straight calcined gypsum, which is used as an addition to lime putty for white-coat work. This is sold as "gaging plaster," sometimes called "stucco," and can be had either unretarded or retarded to set in about 20 minutes.

Calcined gypsum does not work so smoothly under the trowel as could be desired. As a concession to the plasterer, therefore, it has become common practice to add 10 percent to 15 percent of clay or hydrated lime to the material at the mill. The mixture so produced, retarded to set in from one to six hours, is the gypsum plaster of commerce, which is sometimes termed "hard wall plaster." It is also sold as "neat gypsum plaster" in the East and as "cement plaster" in the West. The adjectives "fibered" and "unfibered" denote whether or not any hair or wood fiber has been added to it.

Neat gypsum plaster is designed to be used for the scratch and brown coats of plaster. For this purpose sand must be added to it on the job. For scratch-coat work it is customary to use 1 part of neat plaster by weight to 2 parts of sand; for brown coat the proportions are 1 to 3. Plaster which the sand has been added at the mill is now obtainable. It is known as "gypsum sanded plaster," "ready-mixed scratch coat," or "ready-mixed brown coat."

Another variety is known as "wood-fiber plaster." This is neat gypsum plaster containing about 1 percent by weight of wood fiber. It is designed to be used with or without sand, depending upon the nature of the base or background to which it is to be applied.

Wall plasters and other building materials made of gypsum have a remarkable ability to resist fire.[1] The reason for this is due to the chemically combined water of crystallization, which, as stated, is about 20 percent by weight. The heat breaks up these crystals and liberates the water, the process being slower as the heat penetrates farther into the gypsum. As long as there are any water crystals in the gypsum to be broken up the material will not warm appreciably above the temperature of boiling water.

6. SECOND-SETTLE CALCINED GYPSUM

If, instead of emptying the kettle when the material first subsides in it, the heating is continued, the former phenomena of ebullition and subsidence will be repeated. When the material has settled down the second time no further apparent effect can be obtained by further heating. This material is known as "second-settle calcined gypsum," sometimes called "second-settle stucco."

The reaction involved in this second calcination is expressed by the equation $2CaSO_4.H_2O+heat=2CaSO_4+H_2O$. That is, second-settle stucco is anhydrous calcium sulphate, all of the water having been driven off by the calcination. This substance is identical in chemical composition with the naturally occurring mineral, anhydrite. But there is a vast difference in their physical and chemical properties. To indicate this distinction, second-settle stucco is frequently called

[1] Gypsum as a Fireproofing Material, by Virgil G. Marani, Journal of the Cleveland Engineering Society; November 1914.

"soluble anhydrite." They both have the same crystal form but different optical properties. Both forms react with water, but at extremely different rates. It is a matter of weeks before natural anhydrite can be made to combine with water to form set gypsum. Soluble anhydrite seizes water with avidity. When mixed to a plastic condition it sets more rapidly than calcined gypsum (the hemihydrate). A few minutes exposure to the air suffices for it to absorb enough water to revert to the hemihydrate.

Besides its quicker set, soluble anhydrite has other advantages over calcined gypsum. It requires less water to make it plastic, and consequently makes a harder, denser, stronger set material. Unfortunately, as noted above, it will not keep. Manufacturers tried to put soluble anhydrite on the market, but found that by the time it reached the consumer it had largely reverted to calcined gypsum, so that the extra expense caused by the second calcination was thrown away.

Large quantities of second-settle calcined gypsum are made for immediate use at the mill in the manufacture of precast gypsum tile (plain or reinforced), plaster board, wall board, etc.

7. FURTHER PRODUCTS OF CALCINATION

The change from calcined gypsum to soluble anhydrite occurs at 250 to 300° C. If the heating is prolonged, soluble anhydrite gradually changes its physical structure and becomes natural anhydrite. This is complete just below a red heat.

Natural anhydrite will set if given time enough. It is used in Europe under the name of "flooring gypsum." It sets into a very dense, hard mass, which makes an admirable floor. The American public, however, has not time to wait for it to set, so that it has never been put on the market in this country.

(*a*) *Keene's cement*

Keene's cement is a gypsum product which is used for wall plaster. It sets more slowly than calcined gypsum, but produces a harder, denser surface. The original process for making this material was patented, and therefore a matter of public knowledge, but it is believed that new secret processes have completely replaced the original method. Judging from its composition and behavior, it would seem that Keene's cement is natural anhydrite to which some accelerator such as alum or borax has been added. This material can also be produced by burning select, ground, white gypsum at high temperatures.

Further heating of natural anhydrite to about 1,300° C. will eventually result in its decomposition. Gaseous sulphur trioxide is evolved, and lime remains. This reaction finds no commercial use at present.

8. STRUCTURAL GYPSUM PRODUCTS

(*a*) *Precast Products*

(1) *Gypsum tile.*—The quick-setting property of gypsum and its high strength make it an ideal material to cast into tiles at the mill. These tiles are shipped as such, and laid up to form walls, in the same way as brick or stone. Gypsum tiles come in a great variety of sizes, to suit all purposes. One size commonly used for building

partitions is 12 inches wide by 30 inches long by 3 inches thick. They are usually "cored"—that is, holes run through them longitudinally—although solid tiles can be obtained. These holes are introduced principally to make the tiles lighter, thereby reducing the freight costs and the labor of handling. The air spaces which they form may assist the tile somewhat to resist the transmission of heat. For the same reasons, the tiles are usually made of calcined gypsum in which is included not more than 5 percent, by weight, of wood fiber. This makes them of such a nature that they can be cut with a wood saw. Gypsum tiles must be set in gypsum mortar, made of 1 part calcined gypsum, by volume, to 2 parts of sand. One tile of the material and the dimensions noted above will weight about 30 pounds. When laid on edge, the usual method, it can be expected to carry a load of 1,260 pounds with a large factor of safety. The surface of these tiles are usually roughened to form a key for the plaster.

In the design of precast reinforced gypsum tile, strength rather than lightness is the paramount consideration. These tiles do not contain any sand or fiber, and are of solid or cored pattern. They are made of second-settle calcined gypsum, with as little water as possible, so as to develop maximum strength. Tiles of this character are used mainly for roof construction, being covered, of course, with standard roof coverings to protect them from the weather. While certain stock sizes are recognized, it is customary to make the tile to order, so that they will fit into the supporting members of the roof.

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(*b*) *Structural Members Cast in Place*

Gypsum structural members, either plain or reinforced, can be cast in place in a manner similar to that used for pouring concrete. For this purpose, certain peculiarities of the material must be borne in mind. The one underlying principle is that maximum strength can be attained by getting as much gypsum as possible into a given space. A calcined gypsum to which nothing but retarder has been added should be used. Sand is purely an adulterant, the use of which may or may not be justified by the reduced cost. An excess of water is particularly bad; use as little as possible and still have the material workable. The time of set of calcined gypsum can be regulated at will by adding retarder or accelerator in the mixer or mortar box. Gypsum will set without drying out. Its maximum strength is attained when it is set and dry, and is not dependent upon its age. Intelligent use of these three properties enables the contractor to regulate the time of set so that he can remove the forms at his own convenience, and so that each member will be strong enough to take its full load before the superstructure need be erected on it.

9. PACKAGES AND STORAGE

Crushed raw gypsum is usually shipped in bulk. The ground material for land plaster comes in cotton or burlap bags holding 100 pounds each.

The best grades of pure calcined gypsum are shipped in paper-lined wooden barrels, which hold from 250 to 320 pounds net. Neat gypsum plasters come in burlap bags holding 100 pounds or in paper bags holding 80 pounds each. Ready-mixed (sanded) plasters are shipped in burlap bags of 100 pounds.

Calcined gypsum will absorb water; otherwise it would not set and would be of no value. Therefore, when this material must be stored, it is necessary to protect it from the weather. It should even be protected from dampness if it is to be stored for six months or longer. When reasonably protected from moisture, it will keep indefinitely and may be considered as being good until used. Cases are on record where calcined gypsum stored in tin cans or in paper-lined wooden boxes showed no deterioration in 10 years.

Gypsum and Anhydrite

Extracts from Bureau of Mines Information Circular No. 7049, by Forrest T. Moyer, February 1939.

INTRODUCTION

The usefulness of gypsum as a building material has been recognized from the time of the ancient Egyptians, but only within the last 25 years have the distinctive properties that adapt it to a great variety of processed products been recognized and widely utilized by a progressive industry.

The occurrence and uses of anhydrite and gypsum are so intimately related that the production, processing, and utilization of both minerals are discussed in this paper as parts of a single industry, which because of the vastly greater importance of gypsum will hereafter be termed the gypsum industry.

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COMPOSITION AND PROPERTIES

Gypsum and anhydrite are both calcium sulphate minerals that differ chemically only in their water content; gypsum contains combined water and anhydrite does not. The physical properties, although similar, differ sufficiently to provide simple means for identification.

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Standard specifications (A. S. T. M. Designation C 22–25) state that a material shall not be considered gypsum if it contains less than 64.5 percent by weight of $CaSO_4.2H_2O$.

Pure gypsum is colorless to white, but various impurities change its color to shades of gray, brown, red, or pink. It has a hardness of 2 in the Mohs scale and can be scratched with the finger nail. The specific gravity of pure gypsum is 2.3 to 2.4, so that rock gypsum, free from moisture, weighs about 145 pounds per cubic foot. Gypsum crystallizes in the monoclinic system in tabular crystals that exhibit good cleavage (platy) parallel to the principal plane surface. The compressive strength, as determined by the Bureau of Standards on 6-inch cubes of Virginia gypsum, is:

3,224 pounds per square inch when dry and loaded on bed faces.

2,944 pounds per square inch when wet and loaded on bed faces.

2,617 pounds per square inch when dry and loaded parallel to bed faces.

Gypsum is slightly soluble in water, soluble in dilute hydrochloric acid, and insoluble in sulphuric acid. Its solubility in water is increased considerably by the presence of sodium or magnesium chloride.

Gypsum is widely useful because of its peculiar property of losing three-fourths of the combined water on application of moderate heat and its ability, when cooled and made plastic by admixture with water, to be spread, cast, or molded to any desired surface or form and finally to resume its original state by "setting." The heating process is known as calcining and the resulting product as calcined gypsum.

Calcined gypsum

Calcined gypsum, also known as plaster of paris, cement plaster, and erroneously "stucco," is obtained by heating raw gypsum so as to drive off most of the water of crystallization. The quantity of water removed, which determines the properties of the product, is governed by the fineness and purity of the raw material and by the time and temperature of calcination. In commercial practice gypsum is transformed through the following forms: Between 115° and 125° C. (235° and 260° F.), to hemi-hydrate; between 175° and 195° C. (350° and 385° F.), to soluble anhydrite; and, roughly, above 200° C. (395° F.), to insoluble anhydrite, although there is no definite transition temperature for the last change. Hemi-hydrate, the chief constituent of first-settle plaster, recombines readily with water and "sets." Its chemical composition is $CaSO_4.1/2H_2O$ (93.8 percent $CaSO_4$; 6.2 percent H_2O). Soluble anhydrite, the main ingredient in second-settle plaster, is an unstable, hygroscopic form with the composition $CaSO_4$. It reverts rapidly to the hemi-hydrate. Insoluble anhydrite or dead-burned gypsum (anhydrous calcium sulphate) does not recombine readily with water and sets very slowly or not at all. Calcination of gypsum to any of the above forms results in a volume shrinkage which in hemi-hydrate or first-settle material is approximately 16 percent and in soluble anhydrite or second-settle material approximately 20 percent.

First- and second-settle calcined gypsum set in the presence of water with evolution of heat and slight expansion. One theory of setting is that the unstable hemi-hydrate dissolves in the mixing water to produce a supersaturated solution from which the stable hydrated gypsum is precipitated in typical needlelike crystals. These crystals interfinger as they grow larger and bind themselves together to form a solid, relatively hard mass familiar to most people as hard wall plaster or set plaster. A second theory has been advanced that the hemi-hydrate first forms a gel or adsorption complex with the mixing water which is followed by the formation of gypsum crystals from the adsorption complex to result in set plaster. The apparent expansion during setting is about 0.1 to 0.2 percent.

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DEPOSITS IN THE UNITED STATES

More is known concerning gypsum than anhydrite because the prevalence of gypsum at the surface and its economic uses have led to its exploitation. However, the two minerals usually occur intimately associated in bedded deposits, and with increased cover or depth of operations the form of calcium sulphate to be expected is

anhydrite. Recent researches on anhydrite, which is regarded as a detrimental impurity in gypsum, indicate that industrial applications for the mineral are increasing.

Gypsum deposits of good quality and commercial size are so widespread in the United States that the development of a deposit depends largely upon the demand for gypsum and gypsum products in the immediate region of the particular deposit.

Arizona

Gypsum deposits of commercial size and quality occur in Cochise, Pima, and Pinal Counties in southeastern Arizona, Navajo County in east-central Arizona, and Mohave County in the northwestern corner of Arizona. Only a few of the deposits have been developed because of the small demand for gypsum products within the market area. The only active operation at present is working gypsite and rock gypsum near Douglas, Cochise County. Deposits in the Santa Catalina Mountains, Pima County, and near Winslow, Navajo County, have been worked intermittently.

California

Gypsite deposits, most of which are small, occur through most of the coast ranges of California, particularly south of San Francisco Bay. They have been quarried periodically in Fresno, Kern, King, Los Angeles, Merced, Riverside, San Benito, and San Bernardino Counties.

Extensive deposits of rock gypsum are found in Imperial, Inyo, Riverside, and San Bernardino Counties. Smaller deposits have been worked in Fresno, Orange, Santa Barbara, and Ventura Counties. Gypsum beds over 200 feet thick occur in Imperial County north of Plaster City and Maria. In Riverside County a belt of steeply dipping gypsum beds 10 to 100 feet thick extends through the Palen and Maria Mountains where they have been worked. In the Avawatz Mountains, San Bernardino County, rock gypsum beds up to 10 feet thick outcrop over a large area. Near Acme, Inyo County, several gypsum beds 6 to 10 feet thick have been worked along outcrops.

Colorado

Extensive deposits of rock gypsum are found in the western half of Colorado, notably in Larimer, Jefferson, Douglas, El Paso, Pueblo, Fremont, Eagle, Pitkin, Garfield, Rio Blanco, Delta, Montrose, San Miguel, and Dolores Counties. Gypsite occurrences usually are small and are closely associated with outcrops of rock gypsum. Some gypsite has been quarried near Stone City, Pueblo County, and Coaldale, Fremont County. Active operations are located on large deposits of rock gypsum near Arkins, Larimer County, and Howard, Fremont County.

Recently, alabaster of good quality has been obtained from the rock-gypsum beds in Larimer County. The material is dense and compact, has a banded or mottled appearance, and takes a high polish. It is used for making small, carved art objects.

Idaho

Rock-gypsum beds of workable size are reported to outcrop in Washington and Bear Lake Counties. Gypsum of good quality is mined 18 miles southeast of Leadore, Lemhi County.

Iowa

A flat-lying gypsum bed of high quality, which is 10 to 30 feet thick and underlies a large area near Fort Dodge, Webster County, has been developed for a long time. Several mud or otherwise impure bands, vertical joints, and solution channels are the only irregularities in the bed. Near Centerville, Appanoose County, a gypsum bed 10 to 22 feet thick, lying 550 feet below the surface, was worked from 1917 to 1935. Anhydrite is a common associate. Because of the depth and the large amounts of artesian water the bed was difficult to mine.

Kansas

In the vicinity of Blue Rapids, Marshall County, a large area is underlain by a nearly flat-lying bed of gypsum 8 to 9 feet thick that has been worked extensively. Rock-gypsum beds 5 to 14 feet thick have been worked intermittently in southern Dickinson, northern Marion, and eastern Saline Counties, where they occur in two distinct horizons. In southern Kansas a series of gypsum beds 3 to 25 feet thick extends westward from Medicine Lodge, Barber County into Comanche County and southward into Oklahoma. The beds are easily accessible and have been quarried for a number of years.

Small deposits of gypsite several acres in extent and up to 18 feet thick are found chiefly in the central part of the State. Most of them have been worked out.

Michigan

Large deposits of rock gypsum occur at many places in a nearly continuous belt of strata that outcrop around the coal basin occupying the central part of the Southern Peninsula. Areas developed commercially are in Kent, Iosco, and Arenac Counties. In Kent County a series of gypsum beds 6 to 20 feet thick outcrops in a belt from Grand Rapids into eastern Ottawa County. Four of the beds have been developed extensively by quarrying and underground mining.

A gypsum bed 18 to 23 feet thick at Alabaster extends over a large area in southeastern Iosco County and northwestern Arenac County. Drill holes near Alabaster show five or more gypsum beds 4 to 22 feet thick lying below the bed quarried. Near Turner, Arenac County, a bed of commercial thickness lies above the Alabaster quarry bed. Gypsum outcrops extensively on the St. Ignace Peninsula and adjacent islands in Mackinac County.

Montana

Large deposits of rock gypsum occur in Montana, but they have been developed only in Cascade, Fergus, and Carbon Counties. The Cascade County deposits are in lenticular beds up to 15 feet thick. Gypsum is mined at Heath, Fergus County, from a bed 9 to 14 feet thick and near Hanover, in the same county, from beds up to 7 feet thick. In Carbon County gypsum beds from 10 to 50 feet thick have been explored occasionally. Extensive outcrops of thick gypsum beds are reported in Big Horn and Madison Counties.

Nevada

Thick beds of exceptionally pure rock gypsum outcrop in the western and southern parts of the State. The western area lies in Humboldt, Washoe, Pershing, Lyon, and Mineral Counties, where the gypsum has been developed commercially near Lovelocks, Gerlach,

Mound House, Ludwig, and Mason. The beds of this area have thicknesses up to 200 feet, have more or less steep dips, and are associated with limestone. The deposits of the southern area, where beds up to 300 feet thick are found in Clark and Lincoln Counties, have been worked at Arden, Las Vegas, and Moapa. Thick outcrops of gypsum are reported in the bluffs of the Virgin River.

Small deposits of gypsite up to 15 feet thick occur near rock-gypsum outcrops but have been utilized only in the Mound City region.

New York

Workable beds of rock gypsum outcrop in a belt extending from Madison County westward through the intervening counties into Canada just north of Buffalo. The belt is 12 miles wide at Syracuse, Onondaga County, and 20 miles wide at Seneca Falls, Seneca County, and it averages 7 to 10 miles in width through the remaining distance to Buffalo. Gypsum deposits vary in quality and quantity throughout this area, but deposits of high-grade material (over 90 percent) are reported to be limited to several counties in the western section. Eastward the gypsum contains increasing amounts of interbedded thin shale and limestone bands. The gypsum beds range in thickness from an average of 4 or 5 feet in the western part to a maximum of 30 or 40 feet near Syracuse. The increase in thickness is accompanied by a decrease in purity.

The gypsum beds have a southerly dip of 20 to 50 feet per mile, and as the depth of cover increases anhydrite is found. The vertical depth to the upper limit of the anhydrite zone ranges from 100 to 200 feet depending upon the character of the overlying rock.

At present the gypsum is produced by underground mining in the western half of the belt near Akron and Clarence Center in Erie County, Alabama and Oakfield in Genesee County, Garbutt and Wheatland in Monroe County, and Victor in Ontario County.

Ohio

Gypsum deposits have been developed only in the northwestern part of the State, in Ottawa and Erie Counties. There are active operations near Port Clinton and Gypsum in Ottawa County where the gypsum occurs in three beds ranging from 5 to 15 feet in thickness. In Erie County near Castalia, a 12-foot bed of gypsum, some of which has been classed as alabaster, has been mined intermittently.

Oklahoma

Extensive deposits of rock gypsum associated with anhydrite occur in three general areas in the western part of the State. The first area is a line of gypsum hills along the Cimarron River, extending from Canadian County through Blaine, Major, Woodward, Woods, and Harper Counties into Kansas. Three beds 3 to 20 feet thick occur in these hills. The second area extends as a series of low knolls and ridges from Stephens County through Comanche, Grady, Caddo, Washita, and Custer Counties into Dewey County. Important deposits lie in Custer and Washita Counties where beds 40 to 60 feet thick are traceable for several miles. The third area is in the southwest corner of the State in Jackson, Harmon, Greer, and Beckham Counties, where five beds 18 to 25 feet thick in places are reported. There are active gypsum operations near Ideal, Southard, and Watonga, Blaine County, and near Eldorado, Jackson County.

Gypsite deposits are common in the three described areas, but most of them are small except in Jackson County where deposits up to 400 acres in extent and up to 12 feet in thickness occur.

South Dakota

An elliptical outcrop of gypsum-bearing strata extends around the Black Hills in the so-called Red Valley formed by the Spearfish formation. Beds of commercial quality range up to 30 feet in thickness, and some are continuous for long distances. The only active operation is near Piedmont, Meade County, but formerly gypsum was produced near Hot Springs, Rapid City, Black Hawk, and Sturgis. Some gypsite deposits, associated with the rock-gypsum outcrops, attain workable size.

Texas

The three principal gypsum-bearing areas of Texas are: (1) The north-central part extending from Nolan County into Hardeman County; (2) the west part in Hudspeth and Culberson Counties; and (3) the southern and southeastern parts of the State. The north-central belt, which outcrops over an area 20 to 50 miles wide and 150 miles long, is a continuation of the gypsum beds of southwestern Oklahoma. It contains a number of gypsum beds up to 60 feet in thickness. The beds of Culberson and Hudspeth Counties outcrop over large areas and are up to 300 feet thick. In southeastern Texas great thicknesses of gypsum have been reported at depth in oil wells. In Brooks County near Falfurrias a remarkable deposit of selenite, consisting of transparent layers, is said to be over 1,000 feet thick.

Commercial-grade gypsite deposits are commonly associated with the rock-gypsum outcrops. Many of the gypsum plants utilize both materials. There are active gypsum operations near Falfurrias in Brooks County, Longworth and Rotan in Fisher County, Sweetwater in Nolan County, and Acme in Hardeman County. Other plants have operated sporadically in all of the gypsum-bearing belts.

Utah

Gypsum deposits occur in the central and southern parts of the State. Near Nephi and Levan, Juab County, deposits of massive gypsum are 250 to 300 feet thick, and three beds 10 to 50 feet thick outcrop almost continuously from Marti, Sanpete County, to Sigurd, Sevier County. In Emory and Wayne Counties several thick gypsum beds are reported to contain alabaster. A gypsum bed 175 feet thick outcrops from Iron County into Kane County. Other deposits occur in the southern half of the State. Anhydrite is present in the gypsum at Nephi and Levan and is reported from several other localities. Active operations are located near Nephi and Levan, Juab County, and Sigurd, Sevier County.

Virginia

Workable gypsum deposits are found in a narrow belt about 16 miles long in the valley of the North Fork of Holston River in Washington and Smyth Counties. The gypsum occurs as steeply dipping large masses or lenses that attain thicknesses of 50 feet. In places salt is associated with the gypsum. Anhydrite is usually present. Gypsum mines are operated near North Holston, Smyth County, and Plasterco, Washington County.

Wyoming

Gypsum deposits are widespread in the eastern half and the central and north-central parts of the State. More than 800 miles of gypsum-bearing formations are exposed, and throughout this extent gypsum beds of commercial grade up to 20 feet thick are generally present. Gypsite deposits abound in close association with the rock-gypsum outcrops. The only active plant is a gypsite operation near Laramie. In the past other plants have worked both gypsite and rock gypsum near Laramie, Albany County, and Greybull, Big Horn County.

Other States

Formerly gypsum was obtained from extensive deposits in New Mexico and from rather limited deposits in Alaska and Oregon. Occurrences of possible commercial value are reported in Arkansas, Florida, and Louisiana.

FOREIGN DEPOSITS FROM WHICH CRUDE GYPSUM IS IMPORTED

Crude gypsum for processing into products is imported into the industrial Atlantic Coast States from extensive deposits in the Provinces of Nova Scotia and New Brunswick, Canada. It is also imported into California from a deposit on San Marcos Island, Baja California, Mexico, and into Arizona from the adjoining State of Sonora, Mexico. Imports from Italy consist chiefly of alabaster which is quarried in the Communes of Santa Luce and Castellina Marittima.

USES OF GYPSUM

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Calcined

Gypsum that has been heated enough to be partly dehydrated is known as calcined gypsum or plaster of paris and has approximately the chemical formula $CaSO_4.\frac{1}{2}H_2O$. Standard specifications[10] state that calcined gypsum, after it is mixed with water and the paste allowed to set, shall have a tensile strength of not less than 200 pounds per square inch and a compressive strength of not less than 1,000 pounds per square inch. The product of heating or calcination is also commonly called "stucco" within the gypsum industry, but this is a misnomer and should be avoided. Calcined gypsum without further preparation has limited use, but when it is ground and minor amounts of other substances are added as accelerators, retarders, fillers, and binders its uses are varied and extensive and may be divided roughly into those for manufacturing and those for building purposes.

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Building uses

The most important uses of calcined gypsum are in the preparation of gypsum products for building purposes. Calcined-gypsum products are noted for their light-weight, fire-resisting, low-heat-conducting, sound-proofing, and vermin-proofing qualities. The following table[11] lists the results of tests on solid gypsum tile, 6 inches thick

[10] American Society for Testing Materials, Standard Specifications for Calcined Gypsum (Designation C 23-30).

[11] Schweim, Henry J., Gypsum Partition Tile: Gypsum Association, 1928, p. 6.

and 2 feet square, at the Underwriters' Laboratories, Inc., in 1911. The temperatures were taken on the unexposed face of the tile at definite intervals after the beginning of the test.

Furnace temperature, ° F.	Duration of fire, hours, temperature on unexposed face, ° F					
	½	1	1½	2	3	4
1,000	81	82	92	104	129	161
1,300	80	83	94	113	146	178
1,600	80	85	100	121	168	185
1,900	73	80	100	129	179	189
2,200	77	86	108	144	186	208

Modern requirements for rapid building construction and for desirable and durable materials have greatly expanded the gypsum industry.

Gypsum plasters.—The principal use of calcined gypsum is as a plaster for covering interior walls and ceilings of buildings. These wallplasters are prepared from calcined gypsum by adding a retarding agent to control the time of set and a binder to increase the cohesiveness of the plaster when it is made plastic with water. Wall plasters may be classified as neat, wood-fibered, ready-sanded, prepared-finish, molding, insulating, and acoustical plasters for interior use and as staff or stucco for exterior use.

Neat-gypsum plasters are also known as cement plasters. They consist of calcined gypsum, a fiber such as hair, a retarder, and other materials that add plasticity to the plaster. This type is mixed with 2 or 3 parts by weight of sand at the place of use and applied as the scratch and browning coats in plastering practice. Standard specifications (A. S. T. M. Designation C 28–30) for neat gypsum plaster require that not less than 60.5 percent weight of the cementitious material shall be calcined gypsum ($CaSO_4.\frac{1}{2}H_2O$), that the tensile strength shall be not less than 150 pounds per square inch, and that when mixed with three parts by weight of testing sand it shall set in not less than 8 hours or more than 32 hours.

Wood-fibered plasters consist of calcined gypsum, wood fiber, retarder, and other materials that improve plasticity. They may be used with or without an equal weight of admixed sand for the scratch and browning plaster coats. This type is intended for use where sand is expensive or scarce or where an unusual toughness, light weight, and some flexibility of the finished wall or ceiling is desired. Standard specifications (A. S. T. M. Designation C 28–30) state that wood-fibered plasters shall contain not less than 60.5 percent by weight of calcined gypsum and not less than 1 percent by weight of wood fiber made from a nonstaining wood, that it shall set in not less than 1½ hours nor more than 8 hours, and that after setting it shall have a tensile strength of not less than 125 pounds per square inch.

Ready-sanded plaster is neat plaster to which the sand is added at the mill or mixing plant rather than on the job. It is intended for use in localities where suitable sand is expensive or scarce. The following standard specifications (A. S. T. M. Designation C 28–30) apply to gypsum ready-sanded plaster used for the scratch or first coat and for the browning or second coat.

	Scratch coat	Browning coat	
Shall contain not more than	66.66	75	Percent by weight of sand.
Remainder shall contain not less than	60.5	60.5	Percent by weight of calcined gypsum.
Shall set between	1½ and 7	2 and 6	Hours.
After setting shall have a tensile strength of not less than	75	50	Pounds per square inch.

These three classes—neat, wood-fibered, and ready-sanded—may be broadly grouped by their uses as base-coat plasters.

Prepared gypsum finishing plasters are made of calcined gypsum, selected for color and specially prepared for use as the final plaster coat. Additions of plastic material such as clay or talc improve the working qualities. They may or may not be retarded and may require only the addition of water to be ready for application. This type of wall plaster may be subdivided into trowel-finish, which contains no sand; sand-float finish, which contains clean white sand; and gauging plasters, which should only be used when mixed with 2 parts by weight of dry hydrated lime. Standard specifications (A. S. T. M. Designation C 28–30) state that calcined gypsum for use as a finishing coat shall be classed in two grades—white and gray, that it shall all pass a No. 14 sieve and not less than 60 percent a No. 100 sieve, that it shall set when not retarded in 20 to 40 minutes and when retarded in not less than 40 minutes or more than 6 hours, and that its tensile strength after setting shall be not less than 200 pounds per square inch.

Specially colored gypsum finishing plasters are available to the trade in as many as 13 standard shades. They are prepared by adding pigments to the normal plasters.

Molding plasters for building purposes are intended for use in interior embellishments, cornices, moldings, and other ornamental plaster work. They are made from specially selected and prepared calcined gypsum and are ground much finer than other plasters so that the molds or casts will be unusually dense, hard, and durable and will present a smooth-finished surface free from pinholes or voids. Standard specifications (A. S. T. M. Designation C 59–30) state that gypsum molding plaster shall contain not less than 80 percent by weight of calcined gypsum, shall all pass a No. 30 sieve and not less than 90 percent a No. 100 sieve, shall set in 20 to 40 minutes, and shall have a tensile strength after setting of not less than 200 pounds per square inch.

Insulating plasters are specially prepared mixtures of calcined gypsum with other materials or chemicals that are added for their fire-resistant qualities or for attaining light weight in the finished product. Calcined gypsum mixed with asbestos fibers is used as an insulating cover on pipes and boilers. By a patent process certain chemicals are mixed with calcined gypsum to make an insulating plaster. When water is added these chemicals react and liberate a gas that expands the mass to several times its original bulk. As the set of the plaster is timed to take place near the period of greatest expansion the resulting mass is porous, light weight, and full of sealed cavities that act as insulators. A dry insulation product recently developed and sold under several trade names is made by passing scrap wallboard or lath

through a hammer mill. The product is light and fluffy and is poured into the spaces to be insulated.

Acoustical plasters comprise mixtures of calcined gypsum with either chemicals, porous materials, or both. The chemicals react with the water after mixing and form minute interconnected cavities or cells, many of which break through to the surface before the plaster sets. The sound waves are trapped and absorbed in these small, winding passageways. Pumicite or volcanic ash is used as a porous, sound-absorbent material in acoustical plasters. It also acts as a trap for sound waves. Plasters for acoustical uses are substituted for and applied in the same manner as the usual finish plaster coats.

Staff or stucco is a gypsum plaster mixed with excelsior, manila, or other fiber. It is used for the exterior walls of temporary exposition or fair buildings. Additions of cement, glycerin, and dextrine to the staff yield compositions that fit it for massive statuary or smaller art objects and decorative panels.

Keene's cement.—As now manufactured in the United States, Keene's cement is prepared from crude gypsum, selected for color and purity, by calcination at high temperature (595° C. or 1,100° F.) until all the chemically combined water is driven off and the material becomes anhydrous. This calcined product is finely ground, and accelerators of set, such as potash salts, or alum are added. The finished material has unique properties that distinguish it from the ordinary gypsum plaster. It will keep indefinitely, can be retempered (made plastic again) after the initial set has developed, possesses a high compressive and tensile strength, and will take a polish. It is used for hard-finish wall plasters, for making imitation marble, and for ornamental plaster work. Where high strength is not desired it is mixed with various proportions of lime putty and used for the finishing coat. Standard specifications (A. S. T. M. Designation C 61–30) for Keene's cement state that it shall all pass a No. 14 sieve, that not less than 98 percent shall pass a No. 40 sieve and not less than 80 percent a No. 100 sieve, that it shall set in 1 to 4 hours, that it shall have a tensile strength of not less than 450 pounds per square inch, and that it shall contain not more than 2 percent of combined water. Keene's cement was first introduced in England where it is made by calcining gypsum to the hemihydrate or first-settle stage, soaking in a solution of alum or borax, recalcining at about 480° C. (900° F.), and grinding to a fine powder. The names Mack's, Parian, Martin's, or Magand's cement are sometimes applied to products similar to Keene's cement. These various names are used to indicate the different chemicals or solutions used in the preparation of the material.

Estrichgips.—A special type of flooring plaster known as Estrichgips (sometimes termed "hydraulic plaster") is prepared by calcining lump gypsum under oxidizing conditions to a temperature of about 900° C. (1,650° F.). At this temperature some of the gypsum is decomposed to lime (CaO), which remains in the material, and sulphur dioxide (SO^2), which passes off. The quantity of lime in the final product ranges from 4 to 10 percent. Estrichgips has a very slow set and, with tamping, will form a dense, hard, durable mass that is resistant to wear. It is widely used as a flooring plaster in Germany, but so far it has not been used in the United States.

Calcined gypsum that contains fiber or wood shavings in the approximate proportion of 7 to 1 by weight is used for poured-in-place con-

struction of floors and roofs of large buildings. The material is mixed in mixing boxes and poured on removable wooden forms or on gypsum or fiberboard forms which are left in place. The construction is usually reinforced with either galvanized welded wire mesh or wire cables. The completed floor or roof deck is monolithic and may be covered with any type of material.

Gypsum tiles and blocks.—Gypsum tiles and blocks are made in various sizes and designs for flooring, roofing, furring, non-load-bearing partitions, and fireproof covering of columns, beams, and shafts. They are light in weight, fire-resistant, and sound- and heat-insulating, are readily laid, and can easily be cut with a hand saw. Gypsum tiles and blocks may be either solid or hollow (cored). They are made by casting a slurry of calcined gypsum, with or without a filler or aggregate, into molds on a continuous belt or slowly revolving wheel. After the gypsum has set sufficiently, the molds and cores, if used, are removed and the tiles passed through a drying machine from which they emerge ready for use. Some tiles are reinforced by casting the gypsum over metal fabric parallel to the face with rods parallel to the edges.

Roof and floor tiles are available either solid or hollow and in long or short spans. They are usually reinforced with metal fabric or rods or both and may be laid in place on T-shaped subpurlins or on the main purlins. Gypsum plank 2 to 3 inches thick, reinforced with wire mesh and metal tongue-and-groove edges, has been found satisfactory in roof and floor construction.

Partition tiles are obtainable either solid or hollow and in several thicknesses ranging from 2 to 8 inches. The usual width and length are 12 and 30 inches, respectively. Partition tiles are not reinforced and are used only in non-load-bearing walls. Because of their light weight and large uniform size, they are easily and quickly laid in gypsum mortar to yield an even surface ready for plasterwork. Partition tiles are widely used for partition, corridor, and fire-division walls, elevator and stairway enclosures, column and beam covering, and ventilating and heating ducts.

Furring tiles are made hollow or solid in 1½- and 2-inch thicknesses 12 inches wide and 30 inches long. They are secured to the wall with spikes or built-in wall ties.

Special gypsum-tile shapes, known as shoe, soffit, or angle tiles, are used in combination with 2- or 3-inch hollow partition tiles to form a fire-resistant cover for beams and girders.

Floor domes are molded hollow boxes or tiles of reinforced gypsum used as filler in concrete-floor construction. They effect a considerable saving in deadweight construction and yield a smooth surface on the ceiling below.

DEVELOPMENT OF DEPOSITS

Gypsum and anhydrite occur as bedded deposits with large lateral and relatively small vertical dimensions. Anhydrite, which has limited use in the United States, must be treated as an impurity in a gypsum deposit. Therefore anhydrite deposits will not be considered in this section, although they would be amenable to the same considerations and development methods. As commercial gypsum deposits are widely distributed in the United States several important factors should be considered before any development work is done.

Studies of the potential market and its area, and the productive capacity already in the area are necessary to determine whether the production can be assimilated. In most sections of the country the market for gypsum and its products is limited by the nearness of other plants and by freight rates. Other factors are the location of the deposit with respect to transportation and its adaptability to low-cost operating methods.

Prospecting

The purity and extent of the deposit should be proved by adequate sampling and drilling or trenching so that the available tonnage of commercial material may be calculated by multiplying the length, width, and thickness in feet by 145 pounds (approximate weight of 1 cubic foot of gypsum) and dividing by 2,000. Exploratory drilling may be performed satisfactorily by the diamond, churn, or air drill, any of which will provide enough information.

Quarrying

The proper method of development (open-cut or underground mining) is determined by the thickness and attitude (flat or inclined) of the gypsum beds, the type and thickness of overburden, and the topography of the region. Open-cut mining or quarrying is preferred when the gypsum beds are flat-lying or nearly so and have little or no overburden. If the overburden consists of unconsolidated material, such as soil or glacial debris, a greater thickness may be removed economically than if the overburden is consolidated material, such as shale or limestone. This overlying material is removed as far as possible by mechanical stripping (dragline or shovel), followed by hand stripping to clean out irregularities on the top of the gypsum deposit. The overburden is either cast back onto the quarry floor or is hauled to refuse dumps. In some operations where the cover is light the overburden and gypsum are shot down together and separated on the quarry floor. Holes for primary blasting are drilled by churn or air drills the full depth of the bench in a line parallel to and a predetermined distance back of the face. Low-strength dynamite and black blasting powder are the explosives generally used. After the gypsum is broken loose by the primary blast, block-holing or secondary shooting is done to reduce the large blocks to at least one-man size. The broken material is then loaded by hand or mechanical means into cars for transportation to the mill.

Gypsite deposits always lie close to the surface and usually have little or no overburden. As the material is soft and friable it requires no blasting and is worked with power shovel or scraper.

Mining

Where the gypsum beds have a heavy overburden or are inclined so that operations must be carried beneath an increasing thickness of cover, underground methods are usually employed. Underground mining is successful only if the roof is strong enough to require a minimum of timbering. Mine entries are drifts or adits, slopes, or vertical shafts. The room-and-pillar system of mining is common practice on horizontal or slightly pitching beds, but steeply pitching beds are worked by the drift and shrinkage-stoping methods. About 75 percent of the gypsum is extracted in the first mining by the room-and-pillar method which is generally carried to the property limits

before any pillars are pulled. Pillar and roof extraction or second mining is carried on the retreat, recovering as much gypsum as possible before the unsupported roof caves. Total recovery should be about 90 percent.

Drills are of two types, an electric-powered rotating drill using an auger bit and a percussion air drill. According to report undercutting machines are unsatisfactory because the cuttings tend to clog the cutter bars. The rock is broken loose with low-strength dynamite and loaded into mine cars. In vertical-shaft mines the gypsum is raised to the surface by skips, automatic dumping cages or bucket elevators. In adit or slope mines it is raised by belt or pan conveyors, or cable haulage.

PROCESSING

Modern preparation of gypsum for manufacture into calcined products may be divided into the following stages: Crushing and grinding, calcining, regrinding, and mixing. These steps and the various types of machinery used are outlined on the generalized flow sheet (fig. 1). Most of the machinery is standard and is not designed primarily for the gypsum industry. The machines especially adapted to gypsum processing are the calcining kettles and the feeding and conveying equipment for finely ground and calcined gypsum. However, the physical character of gypsum varies from place to place, and care must be taken to select the most suitable equipment.

Crushing and grinding

In recent years crushing and grinding machines have been perfected to eliminate secondary crushing. Impact mills, such as the swing- or rigid-hammer type, and ring-roller crushers are used successfully where run-of-mine rock does not exceed one-man size. These mills reduce the run-of-mine material to minus 1½ inches or smaller, which is suitable-size feed for rotary kilns. Fine-grinding machines have also been improved so as to handle larger feed and reduce it to smaller size than formerly. Buhr and emery mills, which in the past were favorites for fine grinding in the gypsum industry, are rapidly being discarded for the more efficient, high-capacity modern mills. Rotary crushers or "crackers" similar to the familiar coffee mills which were used widely in the industry in the past are also being replaced by impact-type mills.

A combination drying and grinding mill, which is used to some extent in certain industries, has been tried in the gypsum industry where it appears to have possibilities. This mill, which is directly connected with an air separator, utilizes the waste heat from the calcining process and dries and grinds the crude gypsum in one operation. Further application of the principle of drying and grinding in one operation resulted in experimental hammer-type mills in which the temperature was raised sufficiently to calcine as well as grind the gypsum. Thus one operation would replace four conventional stages—drying, grinding, calcining, and regrinding. The product of these experimental grinding-calcining mills is said to be suitable for many of the uses of calcined gypsum made in the usual manner.

Little trouble is experienced in conveying and elevating crude gypsum with standard handling equipment until the fine-grinding stage. However, as the finely ground product tends to "flood" or

"gush," screw and drag-chain conveyors installed in close-fitting pipes are used to convey and feed the material to the bins or calcining kettles. The use of air separators has eliminated the need for some conveying equipment in gypsum plants.

Calcining

The calcining process, accomplished by kettle or rotary kiln in a gypsum plant, is the stage during which part of the water of crystallization is removed from the raw gypsum and the hemihydrate is produced.

Aging plasters

Plasters that require a minimum of water for mixing and setting are desired for casting, molding, gauging, dental, and orthopedic uses. These products are less plastic but more dense than the common gypsum plasters, have greater strength, and have a minimum of voids in the set product. Formerly "second-settle" calcined gypsum was used to obtain the desired properties, but in present-day practice the same qualities are obtained by aging or treating "first-settle" material. To age calcined gypsum it is only necessary to expose the material to air for a period. Artificial aging is accomplished by introducing a predetermined quantity of a chemical salt, such as calcium chloride into the kettle during calcining. This process affords close control of the degree of aging and is said to yield a more uniformly aged plaster than natural processes.

Mixing

Calcined gypsum, as delivered to the mixing hopper, will set within 6 to 35 minutes after the addition of water. Thus, to render the material suitable for commercial use, certain substances are added to regulate the time of set, to act as fillers, and to serve as binders while the gypsum is in the plastic state.

RETARDERS

Retarders of set are added to calcined gypsum to slow the initial set within a desired time range which is determined by the intended use. Several substances may be used to prolong the time of initial set, the more common of which are glue, starch, slaughterhouse tankage, clay, sugar, and gums. Commercial retarder, in general use at present, is a colloid prepared by treating hair, leather scraps, or refuse from stockyards with lime and caustic soda. Retarders are effective by slowing the rate of growth of the gypsum crystals as they form from solution, by temporarily taking up part of the water and later releasing it, or by decreasing the rate of solubility of the hemihydrate in the mixing water.

The amount of retarder that may be added to calcined gypsum ranges up to 15 pounds per ton, depending on climatic conditions and the purity and intended use of the calcined gypsum. Casting and similar plasters require little or no retarder. Finishing plasters contain 1 to 3 pounds of retarder per ton, and fibered and unfibered wall plasters may contain 4 to 15 pounds per ton. Gypsite plasters, because of their high clay content, need only small amounts of retarder. In hot climates or in the summer less retarder is required than in cold climates or in the winter.

ACCELERATORS

Accelerators of set are substances that will speed the set of gypsum plasters by serving as nuclei for the growth of the gypsum crystals or by directly increasing the rate of growth of the crystals. Raw gypsum is a powerful accelerator, especially when added to cold calcined gypsum. Gypsum plaster that has been set and later reground is widely used. Other common accelerators are potassium sulphate, alum, and salt. Casting, molding, dental, and orthopedic plasters usually require the addition of accelerators. In these plasters the accelerator is added dry at the mill.

For emergency additions of retarders or accelerators on the job the most satisfactory method is to dissolve the material in the water to be mixed with the gypsum plaster. This method insures even distribution of the retarder or accelerator, which is necessary to obtain an even set.

FIBERS

Hair, wood, asbestos, sisal, or similar vegetable fibers are added to gypsum plasters intended for base-coat work. They do not increase materially the strength of the finished wall but are of temporary benefit in serving as a binder to the plaster while it is in the plastic state and preventing flowage and waste of the material back of the lath. For this purpose 3 to 6 pounds of hair per ton of plaster are sufficient. Sisal or other fibers are used widely in place of the more expensive hair. Between 25 and 50 pounds per ton of soft nonstaining wood fibers, such as willow or poplar, are added. The wood fibers also serve as a filling agent, increasing the bulk and decreasing the weight of the plaster.

FILLERS

Granulated cork, wood shavings, sawdust, etc., are added to the calcined gypsum chiefly to decrease the weight and improve the heat and sound insulating qualities of the finished product. They are added to calcined gypsum intended for manufacture into gypsum board and block. The sand added to sanded plaster for the scratch and browning coats must be classed as a filler, although three parts of sand may be used for each part of gypsum plaster. Other material, such as clay or talc, may be added to improve the plasticity of wall plasters.

MIXING

In the mixing operation a weighted quantity of calcined gypsum, usually 1 ton, is placed in a hopper built directly over the mixing machine. Weighed quantities of retarder or accelerator, fiber, and filler are then added to the calcined gypsum, and the contents of the hopper are discharged into the mixing compartments. The various ingredients are thoroughly mixed by being agitated by two sets of paddles attached to two parallel horizontal shafts that rotate rapidly in opposite directions. The mixing time should be not less than 1 minute.

The mixed product is then discharged directly to the packer, where it is placed in containers (barrels, cloth sacks, or paper sacks) for distribution. For sacking of plasters, cloth or paper sacks of the multiwall valve type are used. They are filled by automatic packers directly connected with the mixing compartment.

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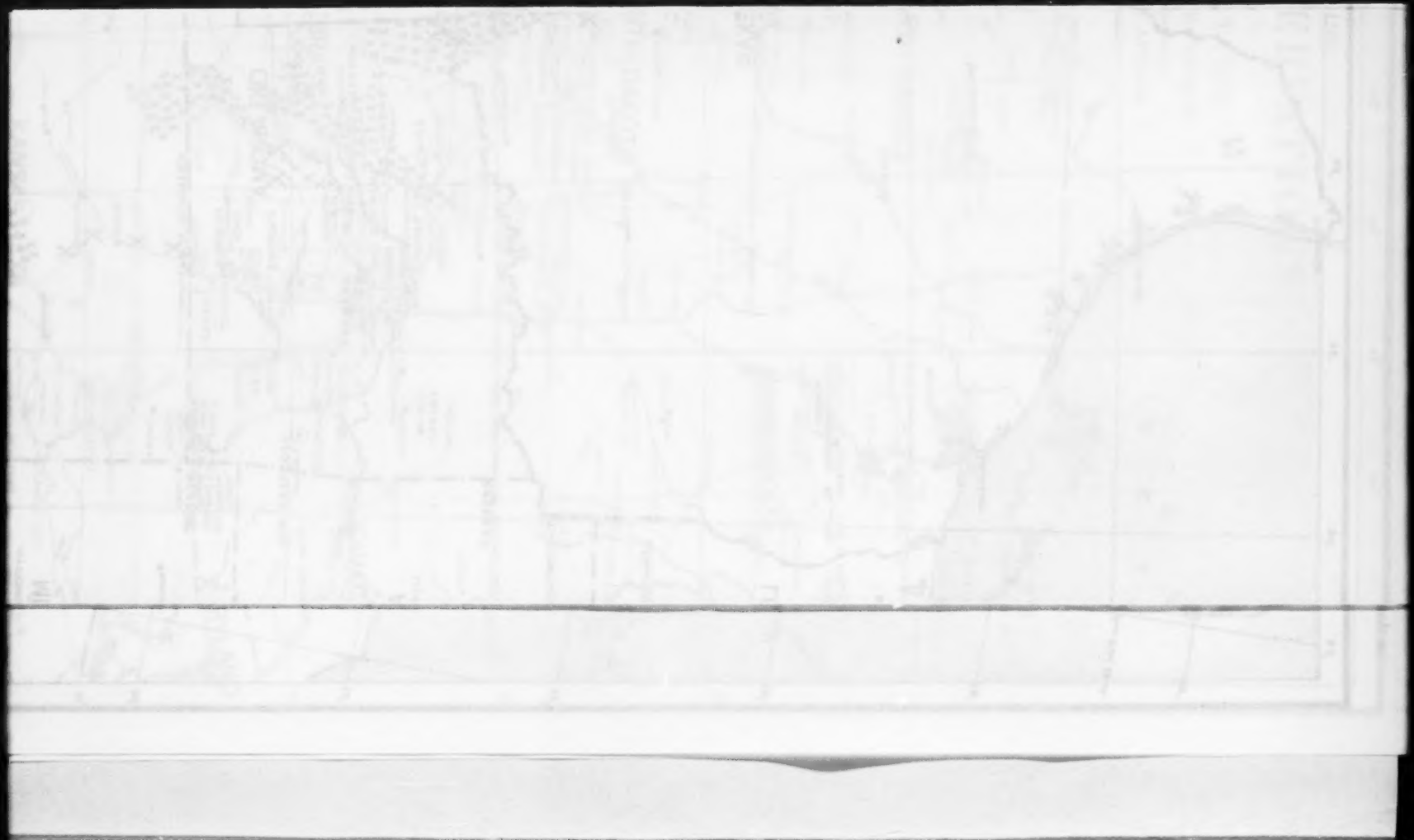

CANADA
PACIFIC OCEAN
WASHINGTON
OREGON
IDAHO
MONTANA
WYOMING
CALIFORNIA
NEVADA
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ARIZONA
NEW MEXICO
MEXICO
LUMMI
Bellingham
Mt. Vernon
TULALIP
Tulalip
Everett
Edmonds
Neah Bay
MAKAH
Port Angeles
Forks
Lapush
Port Gamble
TAHOLAH
QUINAULT
Taholah
SKOKOMISH
TACOMA
OLYMPIA
Auburn
Puyallup
Wenatchee
Cle Elum
Chehalis
Astoria
Longview
YAKIMA
Yakima
Toppenish
PORTLAND
Tillamook
Vancouver
Bonneville
The Dalles
Lyle
Goldendale
CELILO
Pasco
GRAND RONDE-SILETZ
CHEMAWA SCH.
Chemawa
SALEM
Pendleton
UMATILLA
La Grande
WARM SPRINGS
Warm Springs
Madras
Redmond
Bend
Eugene
Marshfield
Burns
Malheur L.
Grants Pass
Klamath Agency
Chiloquin
KLAMATH
Medford
Klamath Falls
Crescent City
Yreka
HOOPA VALLEY
Hoopa
Eureka
Weaverville
Redding
Red Bluff
Alturas
FORT BIDWELL
Fort Bidwell
SUMMIT LAKE
FORT MC DERMITT
McDermitt
ROUND VALLEY
GREENVILLE
Susanville
Fort Bragg
Willits
Willows
Ukiah
UPPER LAKE
HOPLAND
MANCHESTER
LOWER LAKE
Quincy
Reno Junc.
COLONY
Nevada City
Marysville
CARSON CITY
RENO
CARSON
Sparks
Wadsworth
PYRAMID LAKE
Nixon
FALLON
Fallon
YERINGTON
SACRAMENTO
Placerville
Santa Rosa
SAN FRANCISCO
Oakland
Jackson
Stockton
Sonora
TUOLUMNE
WALKER RIVER
Schurz
ALLOTMENTS
YOMBA
Tonopah Jc.
Tonopah
Winnemucca
WINNEMUCCA
BATTLE MOUNTAIN
Battle Mt.
Beowawe
ELKO
Elko
Wells
TE-MOAK
Palisade
RUBY VALLEY
Austin
Eureka
Ely
Duckwater
BIG SANDY
Salinas
Fresno
Bishop
Big Pine
INYO
Independence
COUNTY
Lone Pine
AREA
Beatty
Death Valley Junc.
Porterville
TULE RIVER
San Luis Obispo
Bakersfield
Mojave
Santa Ynez
SANTA YNEZ
Santa Barbara
Sta Barbara Chan.
Barstow
Daggett
LOS ANGELES
Riverside
SHERMAN INST.
San Bernardino
Palm Springs
MISSION
Ramona
Salton Sea
SAN DIEGO
El Centro
FORT YUMA
Yuma
COCOPAH
Las Vegas
MOAPA
Moapa
Lake Mead
Cadiz
CHEMEHUEVI
FORT MOHAVE
Ft. Mohave
Needles
Parker
COLORADO RIVER
Blythe
KOOTENAI
Bonners Ferry
COLVILLE
Nespelem
Coulee Dam
Okanogan
Republic
KALISPEL
Usk
SPOKANE
Wellpinit
Wilbur
Almira
Sandpoint
Coeur d'Alene
Plummer
COEUR D'ALENE
NORTHERN IDAHO
Moscow
Lewiston
Ft. Lapwai
NEZ PERCE
Walla Walla
Ontario
BOISE
Mountain Home
Twin Falls
FORT HALL
Blackfoot
Fort Hall
Pocatello
Idaho Falls
WESTERN SHOSHONE
BLACKFEET
Browning
Glacier Park
Heart Butte
Cut Bank
Shelby
Belton
Kalispell
Polson
FLATHEAD
Dixon
Ravalli
Missoula
GREAT FALLS
HELENA
BUTTE
Logan
Bozeman
Livingston
BILLINGS
Hardin
Crow Agency
CROW
Gardiner
West Yellowstone
Cody
Box Elder
ROCKY BOY'S
Rocky Boy
Havre
Harlem
Agency
FORT BELKNAP
Lewistown
Moran
Worland
Thermopolis
WIND RIVER
Ft. Washakie
Shoshoni
Riverton
Lander
Washakie
Logan
Brigham
OGDEN
Evanston
Granger
Green River
Rock Sprs.
Rawlins
Great Salt Lake
Wendover
SKULL VALLEY
Tooele
SALT LAKE CITY
UINTAH AND OURAY
Heber
Provo
Duchesne
Vernal
Fort Duchesne
Ibapah
GOSHUTE
Gandy
Price
Fillmore
KANOSH
Richfield
Castle Dale
Green River
Crescent
KOOSHAREM
INDIAN PEAK
Lund
Cedar City
Moab
Grand Junction
Montrose
Craig
SHIVWITS
St George
KAIBAB
Kanab
Blanding
CONSOLIDATED UTE
Towaoc
UTE MTN
SOUTHERN UTE
Durango
Ignacio
Pagosa Springs
Monte Vista
Dulce
JICARILLA
Shiprock
Farmington
Kayenta
NAVAJO
Lukachukai
Toadlena
Newcomb
Tuba City
HOPI
Oraibi
Keams Canyon
Chinle
Ft. Defiance
Window Rock
Tohatchi
Crownpoint
Gallup
Ft. Wingate
ZUNI
HUALPAI
HAVASUPAI
Grand Canyon
TRUXTON CANYON
Peach Springs
Valentine
Hackberry
Kingman
Seligman
Ashfork
Williams
Flagstaff
Leupp
Winslow
Holbrook
YAVAPAI
Prescott
Camp Verde
CAMP VERDE
Wickenburg
FORT MC DOWELL
PHOENIX SCH.
PHOENIX
SALT RIVER
PHOENIX SAN.
Globe
FORT APACHE
McNary
White River
SAN CARLOS
San Carlos
PIMA
MARICOPA
GILA RIVER
Sacaton
Coolidge
Casa Grande
Picacho
GILA BEND
Gila Bend
Wellton
Ajo
PAPAGO
SELLS
Sells
Tucson
SAN XAVIER SAN.
San Xavier
Safford
Bowie
Lordsburg
Deming
Las Cruces
Nogales
UNITED PUEBLOS
Bernalillo
ALBUQUERQUE
Laguna
Los Lunas
Puertocito
Socorro
Elephant Butte Res.
Mescalero
Tularosa
Alamogordo
Carrizozo
TAHOLAH AND TULALIP JURISDICTIONS
Scale of Miles
0 10 20 30 40
Vancouver Island
CANADA
Marietta
Bellingham
LUMMI
SWINOMISH

MAP SHOWING

INDIAN RESERVATIONS

= IN THE =

UNITED STATES

DEPARTMENT OF THE INTERIOR

Harold L. Ickes, Secretary

OFFICE OF INDIAN AFFAIRS

John Collier, Commissioner

1941

106° 106° 104° 102° 100° 98° 96° 94° 92° 90° 88°

CANADA

NORTH DAKOTA

SOUTH DAKOTA

NEBRASKA

COLORADO

KANSAS

OKLAHOMA

MINNESOTA

IOWA

MISSOURI

ARKANSAS

ILLINOIS

WISCONSIN

MICHIGAN

MISSISSIPPI

FORT PECK

TURTLE MTN.

FORT BERTHOLD

FORT TOTTEN

STANDING ROCK

CHEYENNE RIVER

CROW CREEK

LOWER BRULE

PINE RIDGE

ROSEBUD

YANKTON

SANTEE

PONCA

WINNEBAGO

OMAHA

SISSETON

WAHPETON SCH

PIERRE SCH

FLANDREAU SCH

PIPESTONE SCH

SIOUX FALLS

TONGUE RIVER

RED LAKE

NETT LAKE

DEER CREEK

VERMILION LAKE

GRAND PORTAGE

WHITE EARTH

LEECH LAKE

RED CLIFF

BAD RIVER

CONSOLIDATED

WILD RICE CAMPS

CHIPPEWA

MILLE LAC

GREAT LAKES

LAC DU FLAMBEAU

LAC COURTE OREILLES

ST CROIX

MOLE LAKE

POTAWATOMI

KESHENA

ONEIDA

STOCKBRIDGE MUNSEE

TOMAH

MINNEAPOLIS

ST PAUL

PRAIRIE ISLAND

UPPER SIOUX

MORTON

SISSETON

WATERTOWN

MILBANK

ABERDEEN

BISMARCK

JAMESTOWN

VALLEY CITY

FARGO

GRAND FORKS

CROOKSTON

DEVILS LAKE

THIEF RIVER FALLS

WILLISTON

MINOT

ROLLA

BELCOURT

WARROAD

INTERNATIONAL FALLS

SAC AND FOX

IOWA

DES MOINES

SAC AND FOX SAN.

KICKAPOO

POTAWATOMI

TOPEKA

HASKELL INST.

KANSAS CITY

JEFFERSON CITY

ST LOUIS

SPRINGFIELD

OSAGE

QUAPAW

PEORIA

MIAMI

OTTAWA

MODOC

SHAWNEE

WYANDOTTE

SENECA

CHEROKEE

FIVE CIVILIZED TRIBES

TULSA

SEQUOYAH SCH.

MUSKOGEE

CREEK

OKMULGEE

SEMINOLE

CHICKASAW

CHOCTAW

PAWNEE

OTOE

PONCA

TONKAWA

KAW

CHEYENNE AND ARAPAHO

SHAWNEE SAN.

KIOWA

COMANCHE

APACHE

WICHITA

CADDO

ARKANSAS CITY

PONCA CITY

ENID

GUTHRIE

OKLAHOMA CITY

LAWTON

ANADARKO

MCALESTER

ARDMORE

WICHITA FALLS

LITTLE ROCK

PINE BLUFF

TEXARKANA

EL DORADO

FORT SMITH

MEMPHIS

DUBUQUE

DAVENPORT

ROCK ISLAND

CEDAR RAPIDS

IOWA CITY

TOLEDO

AMES

FORT DODGE

MASON CITY

LA CROSSE

PORTAGE

BLACK RIVER FALLS

OSHKOSH

GREEN BAY

MANITOWOC

MILWAUKEE

MADISON

PRAIRIE DU CHIEN

BEOIRE

MOBERLY

SPRINGFIELD

PEORIA

QUINCY

CAIRO

PHILADELPHIA

DENVER

COLORADO SPRINGS

PUEBLO

LA JUNTA

GARDEN CITY

DODGE CITY

GREAT BEND

LARNED

HUTCHINSON

NEWTON

EMPORIA

SCOTT CITY

COLBY

LIMON

TRINIDAD

RATON

SANTA FE

ALBUQUERQUE

TUCUMCARI

AMARILLO

CLOVIS

ROSWELL

CARLSBAD

LUBBOCK

HOBBS

ALLIANCE

SCOTTSBLUFF

TORRINGTON

CHEYENNE

FORT COLLINS

STERLING

JULESBURG

LA SALLE

NORTH PLATTE

GRAND ISLAND

KEARNEY

HASTINGS

LINCOLN

COLUMBUS

FREMONT

OMAHA

FALLS CITY

SIOUX CITY

PONCA

NIOBRARA

WINNEBAGO

NORFOLK

WAYNE

WAYNE

WINNER

GREGORY

MARTIN

PINE RIDGE

WHITE CLAY

CROOKSTON

VALENTINE

CHADRON

CRAWFORD

RUSHVILLE

GREENWOOD

LAKE ANDES

WAGNER

YANKTON

CANTON

MITCHELL

CHAMBERLAIN

MURDO

VIVIAN

RADANCE

KADOKA

WANBLEE

KYLE

INTERIOR

NEWCASTLE

CUSTER

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STURGIS

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SHERIDAN

GILLETTE

NEWELL

HIGHMORE

GETTYSBURG

CHEYENNE AGENCY

LAPLANT

MOBRIDGE

ABERDEEN

WILLMAR

GRANITE FALLS

MANKATO

ROCHESTER

LA CROSSE

BROOKINGS

FLANDREAU

PIPESTONE

WORTHINGTON

SPENCER

ESTHERVILLE

ALGONA

MASON CITY

DUBUQUE

DECORAH

WATERLOO

MARSHALLTOWN

GRINNELL

NEWTON

OSKALOOSA

OTTUMWA

CENTERVILLE

CHARITON

CORNING

CLARINDA

SHENANDOAH

RED OAK

ATLANTIC

AVOCA

CARROLL

DENISON

SIOUX CITY

ONAWA

LE MARS

SPENCER

ESTHERVILLE

ALGONA

FORT DODGE

AMES

BOONE

NEVADA

MARSHALLTOWN

GRINNELL

NEWTON

OSKALOOSA

KNOXVILLE

CENTERVILLE

CHARITON

CORNING

CLARINDA

SHENANDOAH

RED OAK

ATLANTIC

AVOCA

CARROLL

DENISON

ONAWA

LE MARS

MOBERLY

KIRKSVILLE

MEXICO

FULTON

JEFFERSON CITY

SEDALIA

WARRENSBURG

CLINTON

HARRISONVILLE

ST JOSEPH

MARYVILLE

CAMERON

PLATTSBURG

KINGSTON

GALLATIN

TRENTON

CHILLICOTHE

BRUNSWICK

MACON

MOBERLY

KIRKSVILLE

HANNIBAL

PALMYRA

MONTICELLO

QUINCY

CANTON

MACOMB

GALESBURG

KEWANEE

PEORIA

BLOOMINGTON

LINCOLN

SPRINGFIELD

DECATUR

CHAMPAIGN

DANVILLE

TERRE HAUTE

VINCENNES

EVANSVILLE

NEW ALBANY

LOUISVILLE

ELIZABETHTOWN

BOWLING GREEN

HOPKINSVILLE

PADUCAH

CAIRO

MURPHYSBORO

CARBONDALE

HERRIN

MARION

CENTRALIA

EFFINGHAM

MATTOON

CHARLESTON

MOUNT VERNON

OLNEY

FAIRFIELD

ROBINSON

CRAWFORDSVILLE

LAFAYETTE

KOKOMO

MARION

WABASH

PERU

LOGANSPORT

PLYMOUTH

ELKHART

SOUTH BEND

GOSHEN

WARSAW

FORT WAYNE

AUBURN

ANGOLA

HILLSDALE

COLDWATER

BATTLE CREEK

KALAMAZOO

BENTON HARBOR

SAUGATUCK

GRAND RAPIDS

MUSKEGON

BIG RAPIDS

LUDINGTON

MANISTEE

TRAVERSE CITY

CADILLAC

ALPENA

GAYLORD

PETOSKEY

CHEBOYGAN

SAULT STE MARIE

MANISTIQUE

ESCANABA

MARQUETTE

IRONWOOD

HURLEY

ASHLAND

SUPERIOR

DULUTH

VIRGINIA

HIBBING

GRAND RAPIDS

BEMIDJI

CASS LAKE

MAHNOMEN

WALKER

DETROIT LAKES

WADENA

BRAINERD

LITTLE FALLS

ALEXANDRIA

FERGUS FALLS

MORRIS

WHEATON

BENSON

WILLMAR

GRANITE FALLS

MONTEVIDEO

ORTONVILLE

MILBANK

WATERTOWN

SISSETON

WAHPETON

LISBON

VALLEY CITY

JAMESTOWN

BISMARCK

MANDAN

DICKINSON

HETTINGER

BOWMAN

MARMARTH

HETTINGER

BOWMAN

MARMARTH

GLENDIVE

MILES CITY

FORSYTH

COLSTRIP

HARDIN

BUSBY

LAME DEER

BIRNEY

ASHLAND

SHERIDAN

BUFFALO

GILLETTE

NEWELL

BELLE FOURCHE

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NEWCASTLE

WORLAND

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RIVERTON

LANDER

DUBOIS

JACKSON

PINEDALE

BIG PINEY

KEMMERER

EVANSTON

ROCK SPRINGS

RAWLINS

ENCAMPMENT

SARATOGA

LARAMIE

CHEYENNE

FORT COLLINS

STERLING

JULESBURG

LA SALLE

GREELEY

BOULDER

DENVER

COLORADO SPRINGS

PUEBLO

CANON CITY

LEADVILLE

GLENWOOD SPRINGS

GRAND JUNCTION

DELTA

MONTROSE

OURAY

SILVERTON

DURANGO

CORTEZ

TELLURIDE

GUNNISON

SALIDA

WALSENBURG

TRINIDAD

RATON

SANTA FE

LAS VEGAS

ALBUQUERQUE

GALLUP

GRANTS

LOS LUNAS

SOCORRO

TRUTH OR CONSEQUENCES

ALAMOGORDO

LAS CRUCES

ROSWELL

CARLSBAD

ARTESIA

HOBBS

LOVINGTON

CARRIZOZO

TUCUMCARI

CLOVIS

PORTALES

FARMINGTON

AZTEC

BLOOMFIELD

SHIPROCK

CHINLE

GANADO

KAYENTA

TUBA CITY

WINSLOW

HOLBROOK

SNOWFLAKE

SHOW LOW

ST JOHNS

GALLUP

GRANTS

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KAYENTA

TUBA CITY

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HOLBROOK

SNOWFLAKE

SHOW LOW

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WILLCOX

BENSON

TUCSON

NOGALES

DOUGLAS

BISBEE

SIERRA VISTA

SAFFORD

THATCHER

GLOBE

MIAMI

SUPERIOR

CASA GRANDE

FLORENCE

COOLIDGE

PHOENIX

MESA

TEMPE

CHANDLER

GILA BEND

AJO

SELLS

SACATON

PARKER

BLYTHE

NEEDLES

KINGMAN

SELIGMAN

PRESCOTT

CLARKDALE

CAMP VERDE

SEDONA

FLAGSTAFF

WILLIAMS

GRAND CANYON

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MONUMENT VALLEY

BLANDING

MONTICELLO

MOAB

PRICE

HELPER

CASTLE DALE

EMERY

GREEN RIVER

VERNAL

ROOSEVELT

DUCHESNE

HEBER

PROVO

SPANISH FORK

NEPHI

FILLMORE

DELTA

MILFORD

BEAVER

PANGUITCH

CEDAR CITY

ST GEORGE

LOGAN

BRIGHAM CITY

OGDEN

SALT LAKE CITY

TOOELE

WENDOVER

WELLS

ELKO

WINNEMUCCA

LOVELOCK

FALLON

FERNLEY

RENO

CARSON CITY

VIRGINIA CITY

YERINGTON

HAWTHORNE

TONOPAH

GOLDFIELD

BEATTY

LAS VEGAS

BOULDER CITY

HENDERSON

OVERTON

MESQUITE

CEDAR CITY

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BLYTHE

PARKER

SACATON

SELLS

AJO

GILA BEND

TEMPE

MESA

PHOENIX

COOLIDGE

FLORENCE

CASA GRANDE

SUPERIOR

MIAMI

GLOBE

SAFFORD

THATCHER

SIERRA VISTA

BISBEE

DOUGLAS

NOGALES

TUCSON

BENSON

WILLCOX

SAN DIEGO

LOS ANGELES

SAN BERNARDINO

RIVERSIDE

SANTA ANA

LONG BEACH

PASADENA

SAN FERNANDO

SANTA BARBARA

VENTURA

OXNARD

SAN LUIS OBISPO

PASO ROBLES

SALINAS

MONTEREY

SAN JOSE

SAN FRANCISCO

OAKLAND

BERKELEY

RICHMOND

SAN RAFAEL

SANTA ROSA

PETALUMA

NAPA

VALLEJO

SACRAMENTO

STOCKTON

MODESTO

MERCED

FRESNO

HANFORD

VISALIA

TULARE

BAKERSFIELD

MOJAVE

LANCASTER

PALMDALE

VICTORVILLE

BARSTOW

TWENTYNINE PALMS

INDIO

BANNING

HEMET

SAN JACINTO

ESCONDIDO

OCEANSIDE

CARLSBAD

SAN DIEGO

CHULA VISTA

EL CENTRO

CALEXICO

BRAWLEY

HOLTVILLE

YUMA

WELLTON

SACRAMENTO

STOCKTON

MODESTO

MERCED

FRESNO

HANFORD

VISALIA

TULARE

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OCEANSIDE

CARLSBAD

SAN DIEGO

CHULA VISTA

EL CENTRO

CALEXICO

BRAWLEY

HOLTVILLE

YUMA

WELLTON

MAP SHOWING

INDIAN RESERVATIONS

= IN THE =

UNITED STATES

DEPARTMENT OF THE INTERIOR

Harold L. Ickes, Secretary

OFFICE OF INDIAN AFFAIRS

John Collier, Commissioner

1941

116° 114° 112° 110° 108° 106° 104° 102° 100° 98° 96°

A N A D A

MONTANA

NORTH DAKOTA

SOUTH DAKOTA

MINN

IDAHO

WYOMING

NEBRASKA

COLORADO

KANSAS

OKLAHOMA

UTAH

NEW MEXICO

ARIZONA

BLACKFEET

ROCKY BOY'S

FORT BELKNAP

FORT PECK

TURTLE MTN.

FORT BERTHOLD

FORT TOTTEN

DEVILS LAKE

FLATHEAD

GREAT FALLS

HELENA

BUTTE

BILLINGS

CROW

TONGUE RIVER

STANDING ROCK

CHEYENNE RIVER

SISSETON

WAHPETON SCH

FORT HALL

WIND RIVER

UINTAH AND OURAY

SALT LAKE CITY

OGDEN

KOOSHARAM

INDIAN PEAK

SHIVWITS

KAIBAB

CONSOLIDATED UTE

SOUTHERN UTE

JICARILLA

HOPI

NAVAJO

HAVASUPAI CANYON

HUALAPAI

FORT APACHE

SAN CARLOS

PIMA MARICOPA

PHOENIX SCH.

PHOENIX SAN.

FORT MC DOWELL

SALT RIVER

GILA RIVER

PAPAGO

SELLS

SANTA FE

ALBUQUERQUE

UNITED PUEBLOS

ZUNI

CAMP VERDE

YAVAPAI

PUEBLO

DENVER

FORT COLLINS

SKULL VALLEY

GOSHUTE

CROW CREEK

LOWER BRULE

PIERRE SCH.

RAPID CITY

SIOUX SAN.

ROSEBUD

PINE RIDGE

FLANDREAU SCH.

PIPESTONE SCH.

SIOUX FALLS

YANKTON

SANTEE

PONCA

WINNEBAGO

OMAHA

SIOUX CITY

LINCOLN

CHEYENNE AND ARAPAHO

CHEROKEE

OSAGE

PONCA

TONKAWA

PAWNEE

SHAWNEE

SHAWNEE SAN.

POTAWATOMIE & SHAWNEE

KIOWA

CHICKASAW

SEMINOLE

IOWA

SAC & FOX

KICKAPOO

CHILOCCO SCH.

ARKANSAS CITY

WICHITA FALLS

LUBBOCK

AMARILLO

CLOVIS

ROSWELL

CARRIZOZO

MESCALERO

TUCUMCARI

LAS VEGAS

TAOS

PECOS

JICARILLA

NAVAJO

TOHATCHI

GALLUP

WINDOW ROCK

FT. DEFIANCE

CHINLE

TUBA CITY

KAYENTA

SHIPROCK

FARMINGTON

DURANGO

MONTE VISTA

ALAMOSA

TRINIDAD

LAMAR

GARDEN CITY

DODGE CITY

GREAT BEND

SCOTT CITY

LIMON

COLBY

ALLIANCE

SCOTTSBLUFF

NORTH PLATTE

GRAND ISLAND

KEARNEY

HASTINGS

FREMONT

COLUMBUS

YORK

MINOT

WILLISTON

DICKINSON

BISMARCK

JAMESTOWN

VALLEY CITY

FARGO

GRAND FORKS

CROOKSTON

THIEF RIVER FALLS

WARROAD

ABERDEEN

MOBRIDGE

GETTYSBURG

HIGHMORE

WATERTOWN

MILBANK

BROOKINGS

MITCHELL

YANKTON

CANTON

WATERTOWN

WILLMAR

GRANITE

MISSOULA

KALISPELL

HAVRE

HARLEM

GLASGOW

WOLF POINT

SHELBY

CUT BANK

BROWNING

GLACIER PARK

BOLTON

COEUR D'ALENE

POLSON

DIXON

RONAN

LAUREL

LIVINGSTON

BOZEMAN

MILES CITY

FORSYTH

GLENDIVE

SHERIDAN

BUFFALO

WORLAND

THERMOPOLIS

RIVERTON

SHOSHONI

LANDER

CASPER

DOUGLAS

WHEATLAND

TORRINGTON

NEWCASTLE

SUNDANCE

BELLE FOURCHE

SPEARFISH

CUSTER

HOT SPRINGS

EDGEMONT

OELRICHS

PINE RIDGE

WHITE CLAY

CHADRON

CRAWFORD

RUSHVILLE

VALENTINE

MARTIN

WINNER

GREGORY

WINNER

GREENWOOD

BLACKFOOT

IDAHO FALLS

POCATELLO

TWIN FALLS

MORAN

WEST YELLOWSTONE

GARDINER

LOGAN

BRIGHAM

GRANGER

ROCK SPRS.

GREEN RIVER

EVANSTON

KEMMERER

LYMAN

MANILA

VERNAL

DUCHESNE

PROVO

HEBER

TOOELE

PRICE

CASTLE DALE

FILLMORE

KANOSH

RICHFIELD

GREEN RIVER

CRESCENT

GRAND JUNCTION

MOAB

MONTROSE

DELTA

GUNNISON

SALIDA

CANON CITY

PUEBLO

LA JUNTA

TRINIDAD

RATON

SPRINGER

CIMARRON

ELKHART

LAMAR

WALSENBURG

ALAMOSA

MONTE VISTA

DURANGO

CORTEZ

BLANDING

KANAB

CEDAR CITY

LUND

ELY

WELLS

WINNEMUCCA

BATTLE MTN.

AUSTIN

FALLON

NEVADA

CARSON

RENO

WASHOE

WALKER LAKE

MINERAL

ESMERALDA

LOVELOCK

PYRAMID LAKE

SUSANVILLE

ALTURAS

MODOC

TULELAKE

KLAMATH

KLAMATH FALLS

CHILOQUIN

WARM SPRINGS

MADRAS

PENDLETON

UMATILLA

PORTLAND

SALEM

GRANDE RONDE

SILETZ

COOS BAY

ROSEBURG

GRANTS PASS

MEDFORD

SISKIYOU

HOOPA VALLEY

ARCATA

EUREKA

CRESCENT CITY

TULE LAKE

YAKIMA

TOPPENISH

WAPATO

SPOKANE

COLVILLE

NESPELEM

OMAK

CHELAN

WENATCHEE

ENTIAT

QUINAULT

TAHOLAH

NEAH BAY

PUYALLUP

PUGET SOUND

TACOMA

SEATTLE

EVERETT

MARYSVILLE

TULALIP

PORT GAMBLE

PORT ANGELES

NEAH BAY

LAPWAI

NEZ PERCE

KOOTENAI

COEUR D'ALENE

SPOKANE

COLVILLE

NESPELEM

OMAK

CHELAN

WENATCHEE

ENTIAT

YAKIMA

TOPPENISH

WAPATO

QUINAULT

TAHOLAH

PUYALLUP

PUGET SOUND

TACOMA

SEATTLE

EVERETT

MARYSVILLE

TULALIP

PORT GAMBLE

PORT ANGELES

LAPWAI

NEZ PERCE

KOOTENAI

COEUR D'ALENE

94° 92° 90° 88° 86° 84° 82° 80° 78° 76°

LEGEND

FORT APACHE — Indian reservations, tribal lands	◯ District headquarters
KLAMATH — Indian reservations, allotted in part	Boundaries of district jurisdictions
FORT PECK — Indian reservations, allotted and opened	Hospitals
PAWNEE — Former Indian reservations in Oklahoma	Highways, graveled or better
o Rancherias and Indian reservations too small to show to scale	Secondary roads
◯ Agency headquarters	Railways
★ State capitals	Airways
NAVAJO — Names of agencies and non-reservation schools and sanatoria. Also designates the reservation when the reservation name is the same as that of the agency.	

GYPSUM

X gypsum deposit xxx gypsum-bearing beds

Based primarily on U.S.G.S. Bull. 679, "Gypsum Deposits of the United States." Detailed investigation would disclose additional deposits in some areas.

CANADA

MINNESOTA

WISCONSIN

MICHIGAN

IOWA

ILLINOIS

INDIANA

OHIO

PENNSYLVANIA

NEW YORK

WEST VIRGINIA

MARYLAND

VIRGINIA

KENTUCKY

TENNESSEE

NORTH CAROLINA

SOUTH CAROLINA

GEORGIA

ALABAMA

MISSISSIPPI

ARKANSAS

MISSOURI

LAKE SUPERIOR

LAKE MICHIGAN

LAKE ERIE

GREAT LAKES

RED LAKE

NETT LAKE

DEER CREEK

VERMILION LAKE

GRAND PORTAGE

LEECH LAKE

RED CLIFF

ONTONAGON

L'ANSE

BAY MILLS

FOND DU LAC

BAD RIVER

WILD RICE CAMPS

CHIPPEWA

MILLE LAC

LAC DU FLAMBEAU

LAC COURTE OREILLES

MOLE LAKE

POTAWATOMI

KESHENA

ST CROIX

MINNEAPOLIS

ST PAUL

PRAIRIE ISLAND

MORTON

STOCKBRIDGE MUNSEE

ONEIDA

TOMAH

MENOMINEE

SAC AND FOX

SAC AND FOX SAN.

DES MOINES

KICKAPOO

POTAWATOMI

TOPEKA

KANSAS CITY

HASKELL INST.

JEFFERSON CITY

SPRINGFIELD

QUAPAW

MODOC

SHAWNEE

WYANDOTTE

SENECA

CHEROKEE

SEQUOYAH SCH.

TAHLEQUAH

MUSKOGEE

CIVILIZED TRIBES

CHOCTAW

LITTLE ROCK

TUSCARORA

TONAWANDA

CATTARAUGUS

NEW YORK

OIL SPRING

ALLEGANY

CORNPLANTER

CHEROKEE

MADISON

LANSING

CHICAGO

DETROIT

TOLEDO

CLEVELAND

PITTSBURGH

HARRISBURG

COLUMBUS

INDIANAPOLIS

CINCINNATI

CHARLESTON

FRANKFORT

LOUISVILLE

NASHVILLE

ATLANTA

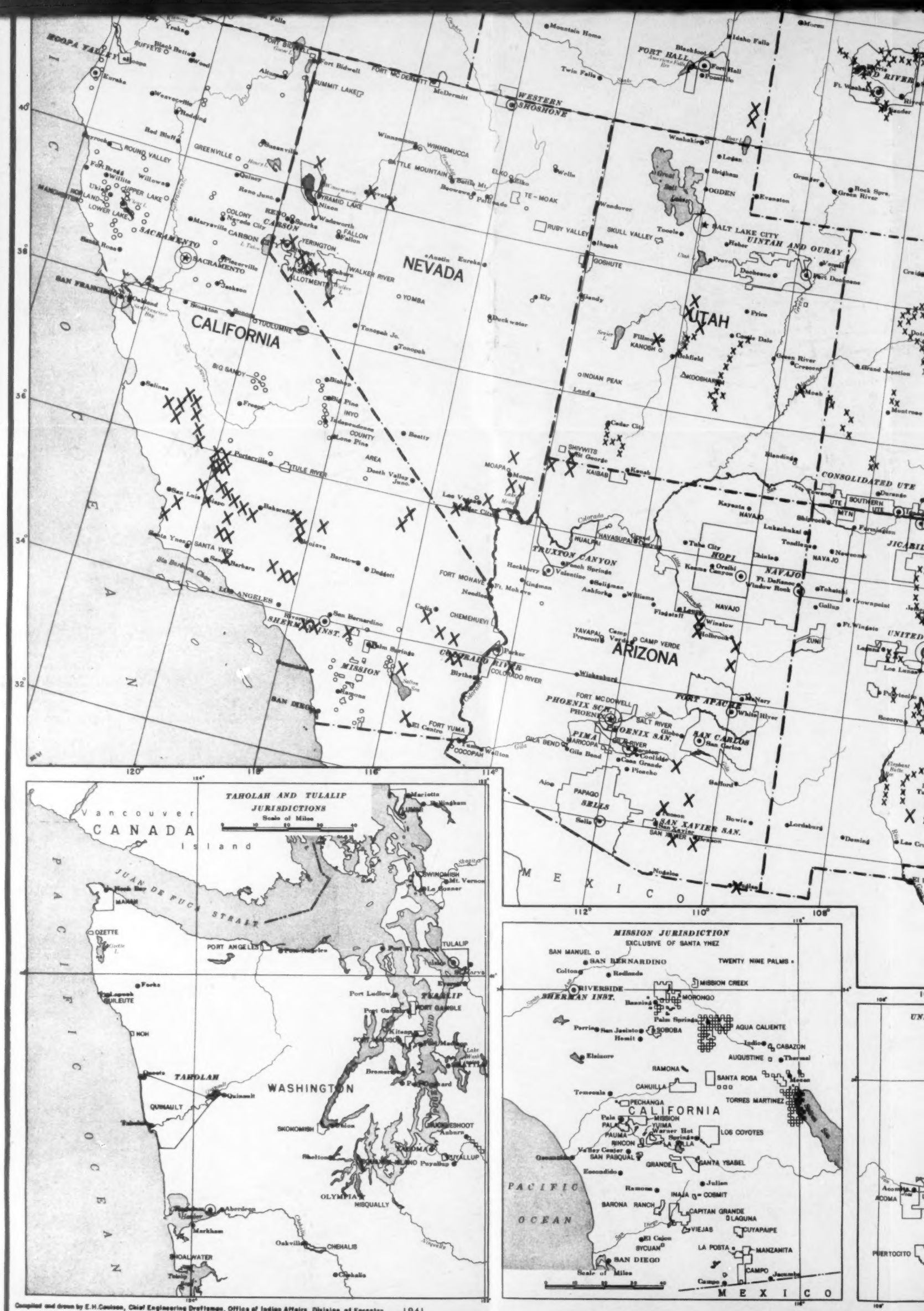
BIRMINGHAM

RALEIGH

COLUMBIA

WASHINGTON

RICHMOND


NEVADA
CALIFORNIA
UTAH
ARIZONA
WASHINGTON
OREGON
IDAHO
COLORADO
NEW MEXICO
MEXICO
PACIFIC OCEAN
Vancouver Island
CANADA
WESTERN SHOSHONE
FORT HALL
UINTAH AND OURAY
SALT LAKE CITY
OGDEN
RUBY VALLEY
GOSHUTE
SKULL VALLEY
TE-MOAK
ELKO
WINNEMUCCA
BATTLE MOUNTAIN
WELLS
WENDOVER
WADSWORTH
FALLON
YERINGTON
RENO
CARSON
PYRAMID LAKE
WALKER RIVER
SUMMIT LAKE
FORT McDERMITT
McDERMITT
FORT BIDWELL
ROUND VALLEY
GREENVILLE
HOOPA VALLEY
SACRAMENTO
SAN FRANCISCO
STOCKTON
SONORA
TUOLUMNE
TONOPAH
ELY
DUCKWATER
YOMBA
AUSTIN
EUREKA
BIG SANDY
BISHOP
BIG PINE
INYO
INDEPENDENCE
LONE PINE
COUNTY
AREA
DEATH VALLEY
BEATTY
FRESNO
SELINAS
PORTERVILLE
TULE RIVER
SAN LUIS OBISPO
SANTA YNEZ
SANTA BARBARA
BAKERSFIELD
MOJAVE
BARSTOW
DAGGETT
LOS ANGELES
SAN BERNARDINO
RIVERSIDE
SHERMAN INST.
PALM SPRINGS
MISSION
SAN DIEGO
IMPERIAL
EL CENTRO
FORT YUMA
COCOPAH
WELLTON
YUMA
PARKER
BLYTHE
COLORADO RIVER
CHEMEHUEVI
NEEDLES
FORT MOHAVE
FT. MOHAVE
KINGMAN
HUALAPAI
HACKBERRY
VALENTINE
TRUXTON CANYON
SUPAI
HAVASUPAI
ASHFORK
SELIGMAN
WILLIAMS
FLAGSTAFF
WINSLOW
HOLBROOK
CAMP VERDE
YAVAPAI
PRESCOTT
JEROME
CLARKDALE
SEDONA
PHOENIX SCH.
PHOENIX
SALT RIVER
PHOENIX SAN.
GILA RIVER
GILA BEND
MARICOPA
PIMA
CASA GRANDE
COOLIDGE
FLORENCE
SAN CARLOS
GLOBE
SAFFORD
PAPAGO
SELLS
AJO
SELLS
SAN XAVIER SAN.
SAN XAVIER
TUCSON
BOWIE
LORDSBURG
DEMING
NOGALES
FORT APACHE
WHITE RIVER
McNARY
SNOWFLAKE
HOPI
NAVAJO
TUBA CITY
KEAMS CANYON
ORAIBI
CHINLE
DEFIANCE
WINDOW ROCK
GANADO
TOHATCHI
GALLUP
CROWNPOINT
NEWCOMB
TOADLENA
SHIPROCK
FARMINGTON
KAYENTA
LUKACHUKAI
CONSOLIDATED UTE
SOUTHERN UTE
MTN
DURANGO
TOWAOC
MONTROSE
GRAND JUNCTION
MOAB
GREEN RIVER
CRESCENT
PRICE
CASTLE DALE
HUNTINGTON
FILLMORE
KANOSH
RICHFIELD
KOOSHARAM
INDIAN PEAK
LAND
CEDAR CITY
SHIVWITS
ST GEORGE
KANAB
KAIBAB
MOAPA
MOAPA
LAS VEGAS
BOULDER CITY
BLANDING
ZUNI
LAGUNA
ACOMA
PUERTOCITO
LOS LUNAS
GRANTS
SAN MANUEL
SAN BERNARDINO
TWENTY NINE PALMS
COLTON
REDLANDS
MISSION CREEK
MORONGO
BANNING
PALM SPRINGS
AGUA CALIENTE
PERRIS
SAN JACINTO
SOBOBA
HEMET
INDIO
CABAZON
AUGUSTINE
THERMAL
ELSINORE
RAMONA
SANTA ROSA
CAHUILLA
TEMECULA
TORRES MARTINEZ
PECHANGA
PALA MISSION
PALA
YUMA
WARNER HOT SPRINGS
PAUMA
RINCON
LA JOLLA
LOS COYOTES
VALLEY CENTER
SAN PASQUAL
GRANDE
SANTA YSABEL
ESCONDIDO
JULIAN
RAMONA
INAJA
COSMIT
BARONA RANCH
CAPITAN GRANDE
LAGUNA
VIEJAS
CUYAPAIPE
EL CAJON
SYCUAN
LA POSTA
MANZANITA
SAN DIEGO
CAMPO
JACUMBA
TAHOLAH AND TULALIP JURISDICTIONS
Scale of Miles
MISSION JURISDICTION
EXCLUSIVE OF SANTA YNEZ
Scale of Miles
MARIETTA
BELLINGHAM
SWINOMISH
MT. VERNON
LA CONNER
SHAGUIA
JUAN DE FUCA STRAIT
PORT ANGELES
TULALIP
PORT GAMBLE
PORT LUDLOW
PUGET SOUND
KITSAP
PORT MADISON
BREMERTON
PORT ORCHARD
SEATTLE
LAKE WASHINGTON
TAHOLAH
QUINAULT
QUEETS
QUILLAYUTE
FORKS
NOOKSACK
SKOKOMISH
SHELTON
SKOKOMISH
SNOHOMISH
MONROE
SNOQUALMIE
FALLS
DUVALLUP
PUYALLUP
OLYMPIA
MISQUALLY
ABERDEEN
HOQUIAM
MARKHAM
OAKVILLE
CHEHALIS
SHOALWATER
TOKELAND
CHEHALIS
HOH
MAKAH
OZETTE
Compiled and drawn by E.H.Couison, Chief Engineering Draftsman, Office of Indian Affairs, Division of Forestry 1941

SOUTH DAKOTA
WYOMING
NEBRASKA
COLORADO
KANSAS
OKLAHOMA
NEW MEXICO
TEXAS
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MISSISSI
Buffalo
Spearfish
Newcastle
Custer
Hot Springs
Edgemont
Shoshoni
Riverton
Rawlins
Laramie
CHEYENNE
Craig
Fort Collins
La Salle
DENVER
Sterling
Julesburg
Limon
Colorado Springs
Salida
PUEBLO
La Junta
Montrose
Monte Vista
Alamosa
Walsenburg
Pagosa Springs
Antonito
Trinidad
Raton
Taos
SANTA FE
Las Vegas
Lamy
ALBUQUERQUE
Tucumcari
Willard
Carrizozo
Clovis
Amarillo
Lubbock
Hobbs
Las Cruces
El Paso
Big Spring
Abilene
Sierra Blanca
San Angelo
Wichita Falls
Fort Worth
Dallas
Tyler
Waco
AUSTIN
San Antonio
Houston
Galveston
Corpus Christi
ALABAMA &
COUSHATTA
Livingston
Woodville
PIERRE
PIERRE SCH.
CROW CREEK
LOWER BRULE
Fort Thompson
Highmore
Huron
Wall
Interior
Kadoka
Murdo
Vivian
Reliance
Chamberlain
Wanblee
Kyle
PINE RIDGE
Martin
ROSEBUD
Rosebud
Winner
Gregory
Pine Ridge
White Clay
Chadron
Crawford
Rushville
Crookston
Valentine
Greenwood
YANKTON
Lake Andes
Wagner
Yankton
Niobrara
PONCA
SANTEE
Alliance
Scottsbluff
North Platte
Grand Island
Kearney
Hastings
Columbus
Fremont
OMAHA
LINCOLN
Norfolk
WINNEBAGO
Winnebago
Ponca
SIOUX CITY
Watertown
Brookings
FLANDREAU SCH.
Flandreau
PIPESTONE SCH.
Pipestone
Mitchell
SIOUX FALLS
Canton
Granite Falls
UPPER SIOUX
MORTON
Prior Lake
PRAIRIE ISLAND
ST. PAUL
Mankato
Rochester
STOCKBRIDGE
MUNSEE
ONEIDA
Black River Falls
TOMAH
Tomah
Oshkosh
La Crosse
Portage
MADISON
Prairie du Chien
Mason City
Fort Dodge
Dubuque
Ames
Toledo
Tama
SAC AND FOX
SAC AND FOX SAN.
Cedar Rapids
Iowa City
DES MOINES
Davenport
Rock Island
Peoria
SPRINGFIELD
Falls City
IOWA
SAC & FOX
Hiawatha
KICKAPOO
St Joseph
POTAWATOMI
Horton
TOPEKA
Lawrence
HASKELL INST.
KANSAS CITY
Moberly
JEFFERSON CITY
ST LOUIS
Emporia
Hutchinson
Newton
Wichita
Colby
Scott City
Great Bend
Larned
Garden City
Dodge City
CHILOCCO SCH.
Arkansas City
Chilocco
KAW
OSAGE
Pawhuska
Ponca City
TONKAWA
PONCA
Enid
OTOE
PAWNEE
Pawnee
TULSA
CHEROKEE
FIVE
CIVILIZED
TRIBES
SEQUOYAH SCH.
Tahlequah
CREEK
Okmulgee
MUSKOGEE
Parsons
QUAPAW
Picher
Joplin
PEORIA
Miami
OTTAWA
MODOC
E SHAWNEE
WYANDOTTE
SENECA
CHEYENNE
AND
ARAPAHO
Clinton
KICKAPOO
El Reno
OKLAHOMA CITY
IOWA
SAC
&
FOX
SHAWNEE
Shawnee
SHAWNEE SAN.
SEMINOLE
Wewoka
Holdenville
McAlester
Wilburton
Talihina
CHOCTAW
Chickasha
Anadarko
KIOWA
Lawton
POTAWATOMI
& SHAWNEE
CHICKASAW
Ardmore
Fort Smith
Ozark
Springfield
LITTLE ROCK
Pine Bluff
Texarkana
El Dorado
Shreveport
Monroe
VICKSBURG
JACKSON
Natchez
BATON ROUGE
Lake Charles
CHITIMACHA
NEW ORLEANS
Memphis
M E X I C O
G U L F O F
UNITED PUEBLOS JURISDICTION
EXCLUSIVE OF ZUNI
TAOS
Taos
PICURIS
Penasco
Chamita
SAN JUAN
SANTA CLARA
SAN ILDEFONSO
POJOAQUE
NAMBE
TESUQUE
SANTA FE
JEMEZ
COCHITI
Penablanca
Domingo
ZIA
SANTA ANA
SANTO DOMINGO
SAN FELIPE
NEW
MEXICO
Bernalillo
SANDIA
CANONCITO
ALBUQUERQUE
Laguna
LAGUNA
Isleta
ISLETA
Los Lunas
Puertocito
Scale of Miles
0 10 20 30 40
106°
104°
102°
100°
98°
96°
94°
92°
90°
30°
28°

WYOMING
NEBRASKA
UTAH
COLORADO
KANSAS
OKLAHOMA
NEW MEXICO
TEXAS
ARIZONA
CALIFORNIA
MEXICO

SALT LAKE CITY
DENVER
CHEYENNE
PUEBLO
ALBUQUERQUE
SANTA FE
AUSTIN
OMAHA
LINCOLN
SIOUX CITY
TOPEKA

FORT HALL
UINTAH AND OURAY
CONSOLIDATED UTE
SOUTHERN UTE
JICARILLA
NAVAJO
HOPI
UNITED PUEBLOS
FORT APACHE
SAN CARLOS
SAN XAVIER
PIMA
PAPAGO
SALT RIVER
PIERRE SCH.
CROW CREEK
LOWER BRULE
ROSEBUD
PINE RIDGE
YANKTON
SANTEE
PONCA
WINNEBAGO
FLANDREAU SCH.
PIPESTONE SCH.
OSAGE
PONCA
TONKAWA
PAWNEE
CHEYENNE AND ARAPAHO
KIOWA
APACHE
COMANCHE
WICHITA
CADDO
SHAWNEE
SEMINOLE
POTAWATOMI & SHAWNEE
IOWA
SAC & FOX
KICKAPOO
POTAWATOMI
CHEROKEE
FIVE CIVILIZED TRIBES
MUSKOGEE
SEQUOYAH
CHICKASAW
CHOCTAW
HASKELL INST.

MISSION JURISDICTION
EXCLUSIVE OF SANTA YNEZ
SAN BERNARDINO
TWENTY NINE PALMS
MISSION CREEK
MORONGO
AGUA CALIENTE
CABAZON
AUGUSTINE
THERMAL
RAMONA
SANTA ROSA
CAHUILLA
TORRES MARTINEZ
PECHANGA
MISSION
YUMA
WARNER HOT SPRINGS
LOS COYOTES
LA POSTA
MANZANITA
CAMPO
JAMUL
SAN DIEGO
SAN LUIS REY
SAN JACINTO
SAN GORGONIO
SAN BERNARDINO
SAN GABRIEL
SAN FERNANDO
SAN BUENAVENTURA
SANTA BARBARA
SANTA YNEZ
SAN LUIS OBISPO
SAN MIGUEL
SAN ANTONIO
SOLEDAD
SAN CARLOS
SAN JUAN BAUTISTA
SANTA CRUZ
SANTA CLARA
SAN JOSE
SAN FRANCISCO
SAN RAFAEL
SONOMA
SAN FRANCISCO SOLANO
MENDOCINO
HUMBOLDT
TULARE
TULE RIVER
KINGS RIVER
FRESNO
KERN
KERN RIVER
TEJON
SAN GABRIEL
SAN BERNARDINO
SAN JACINTO
SAN LUIS REY
PECHANGA
MISSION
YUMA
WARNER HOT SPRINGS
LOS COYOTES
LA POSTA
MANZANITA
CAMPO
JAMUL
SAN DIEGO
MEXICO

UNITED PUEBLOS JURISDICTION
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SAN JUAN
SANTA CLARA
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TESUQUE
SANTA FE
JEMEZ
COCHITI
SANTO DOMINGO
SAN FELIPE
SANTA ANA
ZIA
NEW MEXICO
BERNALILLO
SANDIA
CAÑONCITO
ALBUQUERQUE
ACOMA
LAGUNA
ISLETA
PUERTOCITO
Scale of Miles
0 10 20 30 40

110° 108° 106° 104° 102° 100° 98° 96°

deposits in some areas.

WISCONSIN
MICHIGAN
NEW YORK
IOWA
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
MISSOURI
KENTUCKY
WEST VIRGINIA
MARYLAND
VIRGINIA
TENNESSEE
NORTH CAROLINA
ARKANSAS
SOUTH CAROLINA
MISSISSIPPI
ALABAMA
GEORGIA
LOUISIANA
FLORIDA
ATLANTIC OCEAN
GULF OF MEXICO
LAKE MICHIGAN
LAKE ERIE
LAKE ONTARIO

Prior Lake
PRAIRIE ISLAND
MORTON
Mankato
Rochester
Black River Falls
TOMAH
Tomah
Oshkosh
ONEIDA
Green Bay
Manistique
Ludington
ISABELLA
Mt Pleasant
Bay City
Saginaw
Flint
Muskegon
MILWAUKEE
Grand Rapids
LANSING
DETROIT
Toledo
Kalamazoo
Jackson
Benton Harbor
CHICAGO
South Bend
TOLEDO
CLEVELAND
Akron
Canton
Niagara Falls
BUFFALO
TUSCARORA
TONAWANDA
Syracuse
ONEIDA
MONDAMIN
CATTARAUGUS
NEW YORK
OIL SPRING
Salamanca
ALLEGANY
CORNPLANTER
Erie
Mason City
Prairie du Chien
MADISON
Portage
Fort Dodge
Dubuque
Amana
Toledo
Tama
Cedar Rapids
SAC AND FOX
SAC AND FOX SAN.
DES MOINES
Iowa City
Davenport
Rock Island
Peoria
Ft Wayne
La Fayette
Decatur
SPRINGFIELD
INDIANAPOLIS
Terre Haute
Dayton
COLUMBUS
Parkersburg
WASHINGTON
BALTIMORE
PITTSBURGH
Johnstown
HARRISBURG
Wheeling
St Joseph
Moberly
KANSAS CITY
JEFFERSON CITY
ST. LOUIS
CINCINNATI
CHARLESTON
Evansville
LOUISVILLE
FRANKFORT
Lexington
Lynchburg
Roanoke
RICHMOND
Springfield
Joplin
QUAPAW
MODOC
E SHAWNEE
WYANDOTTE
SENECA
NASHVILLE
Knoxville
Winston-Salem
Greensboro
Durham
RALEIGH
Cherokee
Asheville
CHEROKEE
Bryson City
Charlotte
Greenville
Spartanburg
Florence
Memphis
Ozark
Fort Smith
LITTLE ROCK
Pine Bluff
COLUMBIA
ATLANTA
Augusta
Charleston
BIRMINGHAM
Columbiana
Macon
Texarkana
El Dorado
Philadelphia
CHOCTAW
Shreveport
Monroe
VICKSBURG
JACKSON
Meridian
MONTGOMERY
Columbus
SAVANNAH
Natchez
Laurel
Hattiesburg
Columbia
Waycross
Brunswick
Thomasville
TALLAHASSEE
JACKSONVILLE
Woodville
Lake Charles
BATON ROUGE
Lake Pontchartrain
CHITIMACHA
NEW ORLEANS
Mobile
Saint Augustine
Tampa
Petersburg
Winter Haven
Okeechobee
Lake Okeechobee
Moore Haven
West Palm Beach
Ft Myers
SEMINOLE
Ft Lauderdale
Miami
Florida Bay

Scale of Miles
0 25 50 75 100 125 150 175 200

94° 92° 90° 88° 86° 84° 82° 80°
42° 40° 38° 36° 34° 32° 30° 28° 26°